

SMOKE PREVENTION AND
FUEL ECONOMY

SMOKE PREVENTION AND FUEL ECONOMY

(Based on the German Work of E. Scimiatolla)

BY

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Preface to First Edition

OUR object in writing this book has been to bring before the fuel-using public, as briefly as possible, the principles of fuel combustion, and the means by which the practice of fuel combustion has been carried out, too often with little or no consideration of the physical and chemical conditions involved. The book has grown round our original idea of presenting a simple translation of the German book of Ernst Schmatolla,¹ to which however we have found it necessary to add much to fit the book to English practice, and to subtract other less suitable matter.

We have illustrated also a few examples of British and American appliances, and mechanical stokers, but wish to say that we have employed these merely as illustrations or representatives of a class or type ; not desiring to recommend any appliance further than it appears to fulfil the necessary requirements of thorough mixture of gases and air at a high temperature, the two essentials of complete and perfect combustion. We believe that coal or bitu-

¹ *Rauchplage u. Brennstoffverschwendung*, Gebrüder Jänecke, Hanover, 1902.

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minous quality is capable of perfect combustion, and that black smoke is merely so much evidence of improper design and work. This defect may be due, either to insufficient knowledge of the scientific principles of combustion on the part of the designer, or to parsimony on the part of the buyer and owner of the plant. The former evil we hope to remove by the present book. The latter can only be overcome by a greater insistence that the health and welfare of the general public are of paramount importance, and that they shall not be sacrificed to slight pecuniary gains on the side of the smoke-producer. Smoke prevention is at present possible—in time, it will, we believe, become general.

THE AUTHORS.

WESTMINSTER, LONDON,

September 1, 1904.

Preface to Second Edition

IN bringing out a revised edition of *Smoke Prevention* we take the opportunity to thank both readers and reviewers, for the kind reception accorded to the book on its first appearance seven years ago, and to express our satisfaction that a second edition of the work has been called for. Our aim in revising and bringing the book up to date, has been to render it still more useful to fuel users and to all interested in the black-smoke problem. To that end we have carefully revised the first three Chapters, and have added considerably to Chapter IV and to the first Section of the Appendix. A new Chapter dealing with the legal position and the work of voluntary agencies has also been added to the book, with the view of increasing its value to that growing section of the outside public, which is more interested in the administration of the laws against smoke, than with the technical or scientific side of the subject.

There appears to be nothing new to add in regard to the principles which underlie smoke prevention. This still remains as a result of carrying out in practice the principles enunciated in Chapter II. Patents are apt to fasten upon one of these, to the exclusion of others. The exclusion of one is fatal to success. That of temperature sufficiency is

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perhaps most neglected, and requires most attention from steam-users by way of avoiding too early an abstraction of heat from the burning gases.

The Authors' thanks are due to the Editors and Publishers of *The Times Engineering Supplement*, the *Nineteenth Century and After*, and *The Electrical Review*, for permission to make use of articles which have appeared in the pages of these periodicals; also to Messrs. Sanders, Rehders & Co., and to the Cambridge Scientific Instrument Co., for the loan of photographs.

THE AUTHORS.

LONDON,
July, 1911.

Introduction

FROM the very earliest days of the use of coal the smoke question has been prominent, and laws were enacted to forbid the use of "sea-cole" in London, coal being so named because it was brought by sea from the Tyne Ports. The necessity for fuel and the growing scarcity of wood made all such enactments more or less a dead letter in the sixteenth century, while the nineteenth century legislation against smoke has been practically rendered nugatory by the ignorance of the public, who have come to believe that bituminous coal cannot be burned without producing smoke, and that where, by grace, it can so be burned, there will necessarily be loss.

In the latter part of the eighteenth century it may be supposed that James Watt, when he entered upon practical steam engineering, found the combustion of coal very crudely carried on. The county of Cornwall was the chief steam-using district, owing to its extensive and well-developed mines, which required to be pumped free of water.

The boilers used to generate steam for the pumps were large, circular affairs under which many tons of coal were burning at one time. Trevithick speaks of one such boiler at the Dolcoath Mine, the firegrate

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of which had a grate 22×9 feet, and carried thirty tons of coal on a fire 7 feet thick.

Wales was the source of the coal, and it is probable that the coal was of the so-called smokeless variety, so that there was perhaps little to urge forward any better furnace arrangements. In the use of steam, however, the Cornish engineers appear to have been specially clever, and it is likely that Watt, when introducing his condensing engine, did all he could to secure better boiler conditions, in order that the fullest possible credit might redound to his new system of condensing.

Thus Watt is found to give directions for the proper firing of bituminous coal, and his advice, apart from the form of furnace, is as sound to-day as anything can be.

He recommended that coal be piled upon the dead-plate. There were no fire-doors: the pile of coal served as the door. The heat of the fire beyond caused the more volatile parts of the coal to be driven gradually off.

The pile being porous, some air would be drawn through it and would mingle with the escaping gas and burn with it. In time the pile became wholly or partially coked. The attendant then pushed the fuel onwards over the now decaying fuel on the grate, spreading it evenly over the grate surface, where it would certainly at first give off freely more gas, which would be copiously fed with air from the unclosed furnace opening. The attendant then closed this opening by rapidly shovelling a fresh pile

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of coal upon the dead-plate, and the same cycle of operations was repeated. The boiler to which this furnace was adjunct was first the wagon boiler, so called because of its general form, and later, the plain cylinder with hemispherical ends, usually termed the egg-ended boiler. This rested by means of ears or brackets, riveted near its upper part, upon side walls of brick between which was the firegrate of considerable breadth; this terminated in a roomy dead-plate on which the green coal was piled. The present day dead-plate is a mere rudimentary survival of that of one hundred years ago.

The bottom of the boiler was brought down to within about eighteen inches of the grate surface, a distance that would have been better doubled.

The hot gases enveloped the boiler up to the water level, and usually there was a flash flue, i.e. the gases passed once under the boiler in a single flue with no return side flues.

It will be noted that Watt advocated the "coking" system of firing; that is the gases evolved on the dead-plate and mixed with air, travelled over the length of the bright hot fire and were afforded ample room for combustion in the wide flue beyond, which was bounded on three sides by brickwork. Apart from the cooling effect of the fourth boundary, or boiler bottom, everything was favourable to smokeless combustion. The under-fired boiler endured for some time; indeed, it still serves in the original form at certain collieries and ironworks, and the writer has seen this boiler within

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the past few years still fired as described, and without any other door than the heap of green coal.

An improvement was introduced in the shape of an internal tube passing through the boiler from end to end, and affording so much more heating surface. This tube, by bringing the gases back to the front end of the boiler, necessitated a modified brick-setting, and probably this led up to the two side flues. Another step was to enlarge the inner tube and place the firegrate inside. This produced the Cornish boiler, which was brought out by Trevithick. From it Fairbairn developed the double tube, or Lancashire boiler. In all these modifications the arrangement of the fires and the course of the gases relative thereto, remained the same. It was found, however, that more power could be produced from a boiler, that is to say, it would generate more steam, when the coal was spread over the fire, in place of being coked on the dead-plate. Combustion was more rapid, and smoke was the result. This was partially due to the gradual neglect of steam plant as it became common and familiar, and fell into the hands of less scientific men to attend. Indeed, when Fairbairn founded the Manchester Steam Users' Association in 1854, steam engineering had fallen to a low ebb, coal consumption was excessive, boiler explosions were of alarming frequency, and minor accidents due to broken blow-off pipes were of daily occurrence. Boiler making was the roughest and crudest of arts, and boiler plate was of poor quality; whilst rivet holes were punched, and that

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badly and irregularly, and the worst and most barbaric "drifting" was employed to make openings sufficient to enable a rivet to be entered. In twenty-five years the Association and the Boiler Insurance Companies, which sprang up later, had raised boiler making to a high-class art, and much credit is due, in this connexion, to the late Daniel Adamson, who had the courage to use steel plate, and invented the flanged furnace seam, which made it possible for the Lancashire boiler to maintain its position at the head of all boilers, in respect of all-round safety up to and at the present day. The Lancashire boiler has the correct arrangement of furnace to fit it to burn coal smokelessly, and, if not overpressed, it can be fired smokelessly by a good fireman. To this end it is necessary to provide air-grids in the furnace doors, with an opening of about four square inches for each square foot of grate surface. These openings should be fully open when each fresh charge of fuel has been fired, and they should remain fully open for a short time, and should then gradually close in the course of two to three minutes.

As is always the case in a growing business, the original provision of boilers became too small in most works, and, when over-worked, smokeless firing became more difficult. Adding boilers often demonstrates the smallness of the chimney, and with poor draught the requisite volume of air cannot flow in through the air-grids in the fire-doors.

There was continual rivalry in producing boilers to do a maximum of evaporation, and, one unfortu-

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late day, cross-water tubes made their appearance. These are parallel or taper pipes five or six inches diameter, or four or five to eight or ten inches if tapering, welded or riveted at various inclinations across the furnace tubes of the boiler behind the fire-bridge. They vary from three to fifteen in number. They were claimed to increase the heating surface of a boiler and to promote circulation. Actual experiment has disproved the latter claim, and if there is anything in the former it was more than counterweighted in actual working.

The water-pipes formed lodging for scale, but did the most harm by their bad effect on combustion. They extinguished nascent flame and produced large amounts of soot, and the cross-water tube was fatal to smokelessness. Still worse was the mechanical and physical error of non-circular flue tubes. In this type, an oval flue, incapable of self-support, was propped up by a thickly-spaced forest of cross-water pipes which were most provocative of soot, and were always so covered with it that their surface was of small value as heating surface.

Fortunately this variety of boiler flue is unsuitable for modern pressures, and it has given way to the more practical and scientifically correct circular furnace tube Lancashire boiler, without any cross pipes. The same lack of knowledge of the principles of combustion, however, which gave birth to the cross-water tube, has extended to the present day, and has gained the upper hand. Before the advent of the latter-day water-tube boiler, the question of smoke

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was gradually being brought into line. Water-tube boilers had been tried and found wanting in the matter of smoke. In the United States, however, where the making of boilers is still behind the practice of this country (and it was still further behind a quarter of a century ago), the water-tube boiler was persevered with, and the well-known type of to-day was evolved with its inclined tubes, and, when moderately worked, a fair degree of safety, or at least a danger much less than attached to the discarded Howard safety boiler. But the water-tube boiler in America was the product of the hard coal region. It was made to burn Pennsylvanian anthracite, which is absolutely smokeless, and so far as coal combustion is concerned, the water-tube boiler is all right except for the fact, that even smokeless anthracite should give better results if the furnace gases are all mixed up, so that there may not be too much air at one part and too little at another.

A hard coal furnace produces carbon dioxide, CO_2 , which is colourless. With insufficient air it also produces carbon monoxide, also colourless. With a correct furnace, the latter should be burned by means of the excess of air which may come through bare or thinner parts of the fire. Howbeit, this boiler, which could not make smoke when fired with Pennsylvanian anthracite, was sent over to Great Britain to use bituminous coal, and being set exactly as in America, the results have been hopelessly bad, and the present smoke of London is due to this boiler more than to anything else. It has resulted

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in fines and other difficulties, and, to secure peace, frequently in the use of the best Welsh smokeless coal at double cost. But even with Welsh coal the water-tube boiler will produce bad smoke if badly set. We hope to show in the sequel why this is so, and what is necessary to prevent such results, for the water-tube boiler can easily be made to work without smoke. We shall show something of what has been attempted in the way of preventing smoke, and shall have to deal more or less with questions of furnace forms, draught, systems of mechanical stoking, and other matters which closely interconnect with the subject. Schmatolla, in the book upon which our work is based, has put together something of the principles and practice of fuel combustion in Germany. In that country certainly the scarcity of fuel and the severity of the law, and the scientific training of the men who hold the purse-strings, may account for the better status of the coal combustion question than with ourselves.

It remains, however, a fact that the ordering of coal combustion arrangements in electric light stations and power houses has been sometimes in the hands of men who are electrical engineers chiefly, that they have been at the mercy of boiler makers, and have simply installed steam plant irrespective of all scientific principles. Controlled by committees of no scientific or technical knowledge, or by boards whose ideas have not extended beyond questions of barest first cost, those who have known better have perhaps found themselves hampered for

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want of sufficient appropriations to put in really correct plant. Yet what is possible in Germany should be more easily possible here. With every admiration for certain phases of American practice, however, this admiration cannot be extended to American steam practice in *this* country, for it is to this that we owe our "skies plastered with soot," perhaps a not unnatural result of work done by men who are alien to the country, and look only to a few years' residence here, before returning to America. Still, it is not unreasonable to demand of such the same respect which we ourselves give to life outside mere dollars. We say emphatically, there is no need for smoke. Its production is evidence of neglect of simple laws of chemistry. Smoke can be prevented, and every one should help to enforce the law which says, "thou shalt not smoke." The scriptural hospitality to the stranger within our gates has been freely given. Let us demand of that stranger that at least he shall not break the laws under which he comes unbidden.

Experience shows that smoke can often be prevented by the admission of a very large excess of air. This has been done by admitting it under the grate and through the lower part of the bridge. It appears that the large volume of air enables every particle of gas to secure its requisite of oxygen, but the method is uneconomical and causes undue reduction of temperature in the flues. This brings into prominence the great importance of thorough mixture of the air with the gas. If perfectly mingled

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in the correct chemical proportion, combustion would be perfect without excess of air. This desirable admixture is never attained, but it is approximated in the furnaces of Lancashire boilers, and with good draught and good firing, smokelessness is secured without serious difficulty in boilers without cross tubes. It also appears that combustion is not so rapid when the smaller amounts of air are employed, and it is therefore extended along the flues, and the gases are all the time exposed to cooling by the boiler. Here the importance of temperature appears. It is necessary to conserve the temperature of the gases, until they are in a state of combustion sufficiently active, to maintain such temperature against the cooling effect of the boiler plates. How this has been arrived at in German practice will appear later.

Though the burning of coal in wholly refractory furnaces has been advocated by one of the Authors for years, as the only means whereby smokelessness could be absolutely assured, it appears that the small additional initial expense has been too much for most engineers to face. The external furnace has not always been built with a view to saving the radiant heat, and the *Engineer* in October, 1903, laid it down as a fact that all such attempts have proved a failure, and that no one even knew what became of the heat lost. We need hardly say that this view does not accord with reason or experience, and we are supported by Mr. F. Grover, of Leeds, who conducted an investigation of Bengal coals for

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the Indian Government, and found that such furnaces gave good results. In America they have been

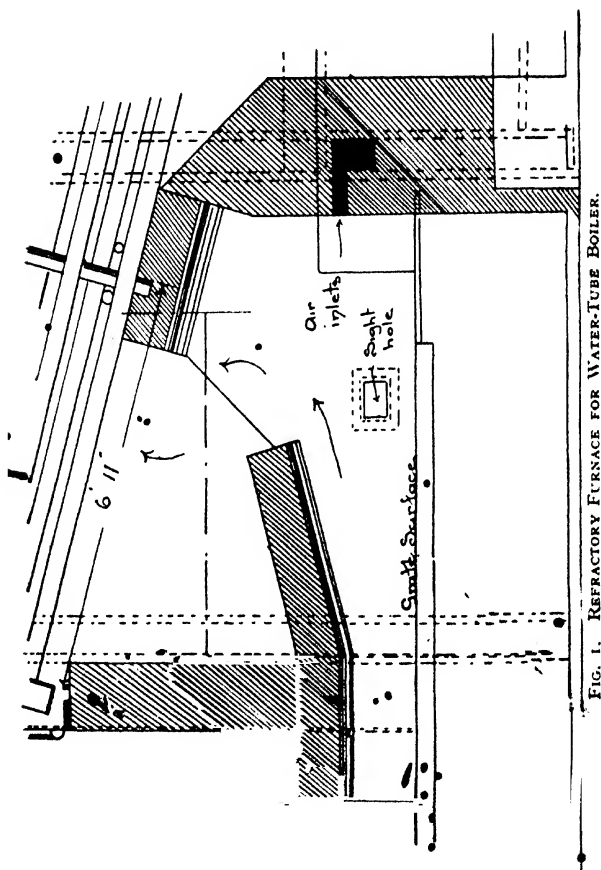


FIG. 1. REFRACTORY FURNACE FOR WATER-TUBE BOILER.

employed under the name of the Dutch oven, and over twenty years ago Mr. Adams, of the Safety

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Valve Works of West Gorton, built a large external furnace to a tubular boiler, with satisfactory results, as seen by one of the authors, but all record of this boiler seems to have disappeared.

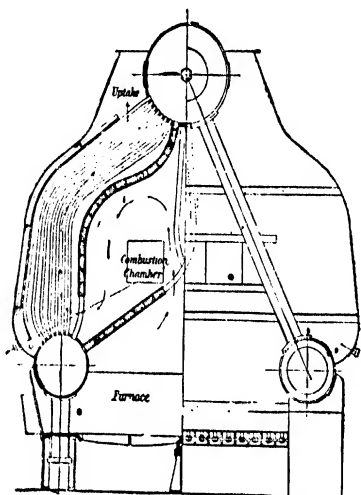


FIG. 2. WEIR SMALL TUBE BOILER, WITH REFRACTORY
LINED FURNACE.

The water-tube boiler setting of Fig. 1 is an example of the refractory furnace, which will convert the water-tube boiler furnace to a state of perfect combustion with economy, and the successful boiler settings will all be noted to include, if not an entire lining of firebrick, at least so much as to secure the end aimed at, namely, temperature. The Weir boiler (Fig. 2) is an example of good setting of a small tube boiler, in which the furnace and com-

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bustion chamber are lined with firebrick, and perfect combustion is secured.

DOMESTIC SMOKE

The solution of the domestic smoke problem hardly comes within the province of this book, but it seems to us that the solution lies in the direction of gas firing. There appears no reason why the suggestion of the late B. H. Thwaite should not be carried out. He proposes to carbonize coal in retorts to the extreme point, by means of exhaustion of the retort carried to the point of depletion of all the volatile gases. He would then convert the coke in separate producers into poor gas, and mix this with the retorted product. In this way all the heating effect of domestic fires would be secured, with the discharge into the atmosphere of water vapour and clean carbon dioxide. The same gas mains would supply gas for heat, light, or power, the second application being rendered possible by means of the incandescent mantle. Some rougher modification of this, however, appears to us to be necessary for a certain class of the population, who would not go to the trouble or expense of renewing the ordinary tender incandescent mantle, and needless almost to say with so much poisonous gas there should be good pipe work and flues that cannot be choked or closed. The difficulties in the way of altering every fireplace to burn bituminous coal without smoke would be so great, that even a cheap and perfect smoke-preventing fireplace would

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be impossible of realization as a popular article. The stove as used in America and Germany is not attractive to the Englishman, and demands special anthracite coal. Gas fuel will give a bright and cheerful fire, and can be arranged for purchase on the penny-in-the-slot system, which has already proved a success with the poorer classes, and offers them a means of purchasing their fuel in small quantities at a fixed price, and thereby protecting them against the extortionate rates charged for fuel sold by the nominal hundred-weight of, too frequently, ninety or even eighty pounds weight. Smokeless combustion on the domestic hearth is at present only to be obtained where a brisk fire is maintained and fresh fuel is brought up from below on the hopper system, whereby the evolved hydrocarbon gases are compelled to travel upward through a thick fire of red-hot coked fuel. With these few remarks, therefore, the subject of domestic smoke must be dismissed as outside the scope of this volume, and only to be treated along special lines. These will be readily understood by those who have grasped the fundamental ideas of air mixture and temperature, without the inclusion of which any scheme of smokeless combustion is impossible. The open grate does not possess these essentials, and even the arrangement foreshadowed above demands a deep red fire and an expensive underhopper of fuel, with an upwinding device that places it beyond the reach of the poor man, who cannot weigh the disadvantages of an immediate first cost against an ultimate advantage in cleanliness and economy.

CHAPTER I

The Chemistry of the Combustion Process

THE prevention of smoke and fuel waste in connexion with industrial heating appliances, either for steam-raising or for other purposes, is dependent upon a clear understanding of the chemical and physical changes which occur during the combustion process, and upon a proper provision for these changes to take place within the combustion area. The smoke and unconsumed gases, which form the most deleterious portions of chimney gases, are due to arrested combustion; that is, to a partial in place of a complete oxidation of the carbon and hydrocarbons of the fuel.

The most important factors in the combustion process are the carbon or carbonaceous constituents of the fuel, and the oxygen of the air.

Carbon, which is represented chemically by the symbol C, is one of the bodies classified by chemists as Elements, and has an atomic weight of 12. In nature, it is only found in the free state as diamond.

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and graphite. When heated in oxygen or in air, it unites with the former, producing two compound gases known as carbon monoxide and carbon dioxide respectively, and in the course of this change it gives out much heat. The process is really one of rapid oxidation. Carbon forms the most important combustible constituent of all natural fuels, and taking these in the order of their age we have the following list: wood, turf, lignite, brown coal, soft or bituminous coal, hard or steam coal, and anthracite. Petroleum and natural gas may also be regarded as fuels, but the exact relation of these to each other and to the solid fuels named above, from the geologist's point of view, has not yet been settled. The distinguished French chemist, Moissan, has put forward a theory that petroleum is formed in the earth's crust by the decomposition of metallic carbides. This is however doubtful.

In wood, or woody fibres, the carbon occurs combined in the form of *Cellulose*. This is represented chemically by the symbol $C_6H_{10}O_5$, and contains carbon, hydrogen and oxygen in the atomic proportions denoted by the figures. Expressed as a percentage, carbon forms 44 per cent. of the total weight in pure cellulose.

The fuels that are produced by the decay of wood and woody fibres, under conditions which hinder the access of air, contain a higher percentage of carbon than the original wood. This percentage of carbon increases as the process of fossilization and decay advances, and it reaches its maximum in

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the fuels which geologists class as the oldest occurring or found in the earth's crust.

In addition to carbon, the natural fossilized fuels contain oxygen and hydrogen, in chemical combination with the carbon, and with each other.

Oxygen (chemical symbol, O, atomic weight 16) is a gaseous element, and forms one of the constituent gases of the atmosphere.

In the free state, it is a gas without colour and without smell. Combined with hydrogen, it forms eight-ninths of the total weight of water on this earth, and in addition it is found in combination in all natural fuels.

Hydrogen (chemical symbol H, atomic weight 1) is also a gaseous element, and is the lightest gas known. It occurs only rarely in nature in the free state. It resembles carbon in being a combustible element; and its combination with oxygen is marked by the liberation of 29,150 calories of heat, and by the production of water.

Nitrogen (chemical symbol N, atomic weight 14) has importance for the combustion process, only as a diluting constituent of the air. This gaseous element is not a supporter of combustion; that is, at moderate temperatures it does not combine with carbon or with oxygen. But under special conditions, it can be made to unite with both of these elements.

The Air is a mixture, not a chemical combination, of oxygen and nitrogen, in the volumetric proportions denoted in round numbers by 21 and 79. One

SMOKE PREVENTION AND FUEL ECONOMY

litre of air weighs 1.293 grammes, and it contains roughly 23 per cent. of oxygen and 77 per cent. nitrogen by weight.

Sulphur occurs as an impurity in most natural fuels, and in coal it is due to the presence of pyrites or "brasses" in the coal seams. It is an elementary substance (chemical symbol S, atomic weight 32), and it burns in oxygen with production of a stifling gas called sulphurous acid, represented by the chemical symbol, SO_2 .

The elementary bodies mentioned above yield, in combination with one another, compounds which may be either solid, liquid, or gaseous, at the ordinary temperature. The combustible element, carbon, when burnt in oxygen or air, yields two compounds, namely carbon mon-oxide and carbon di-oxide; both gases without colour or distinctive smell. Carbon monoxide is formed by the union of one atom of carbon with one atom of oxygen, and is represented by the symbol CO ; while carbon dioxide is formed by the union of one atom of carbon, with two atoms of oxygen, and is represented chemically by the symbol CO_2 . The first of these gases is combustible; that is, it can unite with another atom of oxygen, and then yields CO_2 . Carbon monoxide is a directly poisonous gas, while carbon dioxide is only dangerous as an asphyxiant.

Hydrogen, as already stated, when burnt in oxygen or air, combines with one-half its volume of oxygen and yields water; generally in the gaseous state, or as steam.

CHEMISTRY OF THE COMBUSTION PROCESS

The combinations of carbon and hydrogen yield an important series of chemical compounds known as the hydro-carbons, and play an important part in the combustion process. These hydro-carbons are some of them solid, some liquid, and some of them gaseous, at the normal temperature.

The following are the more important of these compounds, in relation to the combustion of fuel—

Methane or Marsh Gas	.	.	Chemical symbol CH_4
Ethylene or Olefiant Gas	.	.	" " C_2H_4
Acetylene	.	.	" " C_2H_2

The heats of combustion of these hydro-carbons, according to Berthelot, are—

Methane	.	.	.	.	13,343 calories ¹
Ethylene	.	.	.	.	12,182 "
Acetylene	.	.	.	.	12,142 "

In each case, carbonic acid gas and water vapour are produced by their complete combustion in oxygen or air.

Sulphur also forms a gaseous compound with hydrogen, known as sulphuretted hydrogen, when the combustion of a fuel containing much sulphur and hydrogen occurs, without a sufficiency of oxygen (or air) being admitted to the grate. This gas has a distinctive odour, and its presence in the waste

The calorie, or unit of heat, is that amount which is required to raise the temperature of the unit weight of water through 1°C . The unit weight is the gram for the small calorie, and the kilogram for the large calorie. In English practice, the pound and the degree F. are usually employed; and the resultant heat unit is known as the B.Th.U., or British Thermal Unit.

SMOKE PREVENTION AND FUEL ECONOMY

gases is always a sign of imperfect combustion. When an excess of oxygen or air is present at the requisite temperature, sulphuretted hydrogen gas burns to sulphur dioxide and water.

Turning now to a consideration of the chemical changes involved in the combustion of natural or artificial fuels, it is advisable to commence with that of the purest form of carbon. This is found in wood-charcoal and in coke, these products being obtained by the dry distillation (that is, distillation in the absence of air or oxygen) of wood and coal respectively. When either wood charcoal or coke is raised to a temperature of $700^{\circ}\text{C}.$, known as the ignition temperature, in an excess of oxygen or of air, combination occurs between the carbon and oxygen, with production of light and heat, and the wood charcoal or coke is reduced to ash, with change of all the carbon into gaseous carbon dioxide. The following represents the change, in chemical symbols, and the weight and volume of gases evolved, when oxygen is employed—

Chemical equation	$\text{C} + 2\text{O} = \text{CO}_2$
Weights in kilograms	$1 + 2.667 = 3.667$
Volumes in cubic metres	$.9321 + 1.865 = 1.865$

When air is employed the changes are as follows—

Chemical equation	$\text{C} + \text{Air} = \text{CO}_2 + x\text{N}$
Weights in kilograms	$1 + 11.508 = 3.667 + 8.841$
Volumes in cubic metres	$.9321 + 8.897 = 1.865 + 7.032$

¹ $.9321$ is the calculated volume of 1 kg. of carbon, when it has assumed the gaseous state. The kilograms can be changed into pounds avoirdupois by multiplying by 2.204, and the cubic metres can be changed into cubic feet, by multiplying by 35.3.

CHEMISTRY OF THE COMBUSTION PROCESS

When an insufficient supply of oxygen or air is present, the carbon is only converted into carbon monoxide gas, and the chemical and physical results are as follows—

IN OXYGEN—

Chemical equation	$C + O = CO$
Weights in kilograms	$1 + 1.333 = 2.333$
Volumes in cubic metres	$.932^1 + .932 = 1.865$

IN AIR—

Chemical equation	$C + Air = CO + xN$
Weights in kilograms	$1 + 5.754 = 2.333 + 4.421$
Volumes in cubic metres	$.932^1 + 4.448 = 1.865 + 3.516$

The volumes of combustible in the above tables are for carbon in the gaseous state. One kilogram of carbon when burnt to carbon dioxide yields 8,137 calories of heat, while only 2,453 calories are liberated when carbon monoxide is produced. It is customary now to ascribe this deficiency in heat-production, for the union with the first atom of oxygen, to the heat absorption due to the conversion of the carbon from the solid into the gaseous state. The heat which disappears in the performance of this work is 3,231 centigrade units.

Should the carbon monoxide first formed be mixed with the requisite amount of air or oxygen and burnt to CO_2 , the following changes occur—

IN OXYGEN—

Chemical equation	$CO + O = CO_2$
Weights in kilograms	$1 + .571 = 1.571$
Volumes in cubic metres	$.80 + .40 = 1.20$

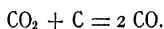
¹ See Footnote on previous page. . .

SMOKE PREVENTION AND FUEL ECONOMY

IN AIR—

Chemical equation	$\text{CO} + \text{Air} = \text{CO}_2 + \text{N}_2$
Weights in kilograms	$1 + 2.463 = 1.571 + 1.892$
Volumes in cubic metres	$.80 + 1.908 = .80 + 1.508$

Carbon monoxide gas can also be formed, by the reduction of carbon dioxide in the presence of red-hot carbon, according to the following equation—



While the formation of carbon monoxide by the direct union of carbon and oxygen produces 2,453 calories of heat, as stated above, the formation of this gas by reduction of carbon dioxide already formed, is a heat *absorbing* reaction, and 3,231 calories of heat disappear in the change. This reduction of carbon dioxide in the presence of heated carbon to carbon monoxide occurs frequently, under certain conditions of fuel utilization; and the reaction is purposely brought about in the various methods of manufacturing "Producer gas" from raw fuel.

It is now necessary to consider the changes involved when water-vapour or steam comes into contact with carbon at a red heat, since this is always present in smaller or larger amounts in the air and fuel, and in many appliances for smoke prevention it is purposely admitted to the furnaces. The chemical equations show that either carbon monoxide, or carbon dioxide, and free hydrogen are produced, carbon dioxide being formed when two molecules of water-vapour react with one atom of

CHEMISTRY OF THE COMBUSTION PROCESS

carbon. The temperature at which this decomposition of water-vapour occurs is between 800° and 1000°C. ; carbon monoxide being formed at the higher temperature. These reactions play an important rôle in the Dowson and Mond gas producers, and in the production of water gas.

In addition to the carbon which is the chief constituent of all natural fuels, these contain considerable percentages of oxygen and hydrogen which remain after the fossilization of the cellulose of the original woody fibre has proceeded through its various stages. The percentage of oxygen, however, diminishes with the age of the fuel, being greatest in peat and lignite, and lowest in anthracite. The percentage of hydrogen does not show such great variation, and it is generally assumed to be present combined with carbon to form hydrocarbons. The most important of these for the fuel user are those already named:—methane, ethylene and acetylene. The exact state in which the oxygen and hydrogen exist in solid fuels has, however, not yet been settled by scientists; but they are at least in a solid state no matter how combined with other elements. For a detailed discussion of this question, see *Liquid Fuel*, by W. H. Booth, 1903, pp. 99–101. The percentage of these hydrocarbons evolved when heating raw fuel is the measure of the difficulty experienced in burning the fuel without smoke. The greater the percentage of volatile hydrocarbons evolved on heating the fuel, the greater is the need for careful design of the furnace in which it is to be used. Table I in the

SMOKE PREVENTION AND FUEL ECONOMY

Appendix contains some valuable information relating to typical English coals, and from this table it will be seen that the percentage of volatile matter varies from 10 per cent. in South Wales steam coal, to 35 per cent. in a North-country slack.

When the necessary conditions for perfect combustion are present, these gaseous hydrocarbons burn completely to carbon dioxide and water. The changes in the case of Methane (CH_4) are as follows—

METHANE IN OXYGEN—

Chemical equation	$\text{CH}_4 + 4\text{O} = \text{CO}_2 + 2\text{H}_2\text{O}$
Weights in kilograms	$1 + 4.000 = 2.750 + 2.250$
Volumes in cubic metres	$1.40 + 2.800 = 1.400 + 2.800$

When air is employed to burn the methane in place of oxygen, the changes are set forth in the next tabular statement.

METHANE IN AIR—

Chemical equation	$\text{CH}_4 + \text{Air} = \text{CO}_2 + 2\text{H}_2\text{O} + x\text{N}$
Weights in kilograms	$1 + 17.26 = 2.750 + 2.250 + 13.26$
Volumes in cubic metres	$1.40 + 13.358 = 1.400 + 2.800 + 10.61$

The combustion of Ethylene and Acetylene follow on similar lines, and it is hardly necessary to present a tabular statement of the changes for each of these gases. The heats of combustion produced by these hydrocarbons have already been given (see p. 33), the heat contained in the aqueous vapour being included in these results.

The ignition points for these gases, according to Mayer and Münch, are—

Methane, 667°C .	Acetylene, 580°C .
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CHEMISTRY OF THE COMBUSTION PROCESS

The formation of visible smoke during the combustion of bituminous coal is due chiefly to the heat absorption that occurs when these gaseous hydrocarbons are formed from the solid constituents of the coal, and also to the lack of the oxygen required for their complete combustion to carbon dioxide and water. If an adequate supply of air, and a sufficiently high temperature, be preserved in the furnace during the liberation of these hydrocarbon gases from the coal, no smoke will be formed.

As regards the intermediate chemical changes that occur during combustion, the investigations that have been carried out by Dixon, Mallard, Le Chatelier, Chapman, Baker, Bone and others during the past fifteen years, have proved that gaseous combustion is a much more complicated chemical process than was formerly supposed. The combustion of fuel is no longer regarded as a series of simple chemical changes in which carbon and hydrogen combine with oxygen to form carbon monoxide or carbon dioxide gas and water, the hydrogen having a selective action when there is a deficiency of oxygen present in the gas mixture. The chemistry of combustion is now regarded as one of the most intricate and remarkable branches of molecular activity, in which gas-films, electrons and ions, all play an important rôle.

A valuable Report upon the results obtained in recent researches on this subject was presented by Professor Bone to the members of Sections A and B at the 1910 meeting of the British Association at

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Sheffield, and readers who desire to follow up this subject are referred to that Report and to the discussion upon it.

For practical purposes it will suffice to know that a sufficiency of oxygen and an adequate temperature will always ensure complete combustion of the hydrocarbon gases.

CHAPTER II

Present Methods of Burning Fuels, and their Defects.

AS will appear later, the practice of fuel combustion for steam-raising purposes has been, and still is, to place the relatively cold surface of the steam boiler very near to the place in which the fuel is undergoing combustion. Thus, in the case of internally-fired boilers, the grate is covered by a semi-cylinder of water-cooled plate, which absorbs heat from the fire and from the unburned or burning gases, and deprives them of so much heat that they are cooled below the ignition point. Otherwise, the internal furnace possesses most of the requisites of perfect combustion, which have been laid down as follows—

1. A draught velocity of not less than thirty feet per second over the fire, to draw in air above the fire bed for combination with the gases distilled from the freshly charged fuel.

2. A thorough mixing of this air with the fuel gas, which can usually be best done by allowing the air and gas to flow together over the length of the

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furnace. The air must be admitted in numerous fine jets, as through a perforated plate in the door.

3. A sufficient temperature to ensure ignition at the bridge end of the furnace.

4. Space in which the combustion can complete itself undisturbed and without loss of too much heat to cold surfaces.

The third requisite is usually more or less absent, owing to the effect of the water-cooled furnace plates.

The fourth requisite in Lancashire boilers is frequently destroyed by the cross pipes in the flue tubes, which have the effect of knocking out the nascent flame. Hence the sootiness when cross pipes are present.

THE WATER-TUBE BOILER

Excepting No. 1, all the above requisites are absent from the *usual* setting of the water-tube boiler, but can be readily applied by a different setting.

Air may enter at the doors, but it does not sweep over the fire surface. The gases rise vertically from the grate and pass unmixed with air between the tubes, which cool them below the point of ignition. The tubes, however, do mix up the gas and air, and these may ignite beyond the boiler, where they can effect no good. The small vertical boiler is obviously of this same faulty design. So also is the locomotive boiler, but this is more or less cured by the insertion of a

PRESENT METHODS OF BURNING FUELS

fire-brick arch that compels the gases to travel round its projecting end and along its heated face, to meet fresh air near the door and burn in the dome of the fire-box. Without the arch, the gases rise directly from the grate, and pass unburned to the cold tubes. In all cases, however, there is seen the close approximation of the boiler to the grate, with an absence of all consideration of that most important requisite, temperature. Such neglect, with bituminous fuel, is productive of visible, more or less black smoke, which tells of early cooling. Black smoke may not in itself indicate a serious loss of actual carbon, but it is certain evidence of sooted heating surfaces, and points to inefficient transfer of heat. Colour alone is, however, not a necessary sign of imperfect combustion. The most imperfect combustion may give colourless furnace gases, the chimney top being quite clear.

In order to avoid smoke production, especially in towns, coke is often employed. Practically a compound of pure carbon and ash, containing no hydrocarbons, it is smokeless. But the use of coke, though it may avoid black smoke, does not necessarily imply perfect combustion. The waste gases from a coke furnace are often heavily charged with carbonic oxide (CO), resulting from too small a supply of air. To ensure bright and active combustion of coke, a fire must be of some depth or thickness. The air fed through the grate at once unites with the glowing fuel. It should always be remembered that when supplied with sufficient air

SMOKE PREVENTION AND FUEL ECONOMY

carbon at once burns to its dioxide, CO_2 . Hence, in passing through the fire all the oxygen is taken up, and when the carbon dioxide has still to traverse a further thickness of glowing fuel, the hot carbon becomes dissolved; the dioxide gas is changed into the monoxide; and the furnace gases pass away to the chimney, after producing less than one-third

of the calorific capacity of the fuel, or 2,453 calories, in place of 8,137; or 4,415 B.Th.U. in place of 14,647.

If, however, air be supplied above the fire, the carbonic oxide will ignite and burn with a clear bluish purple flame, giving out a further 5,684 calories, or 10,232 B.Th.U.

An example of a coke fire is that of Fig. 3, which shows a crucible furnace heated by coke and fed by air below the grate.

All the oxygen will be taken up in the deep fire, and carbonic oxide alone will escape to the flue. If air be admitted above the crucible it will produce the characteristic flame of carbonic oxide, but the heat of this second burning will escape wasted to the flue. Properly to use this heat the coke should be wholly below the crucible, and there

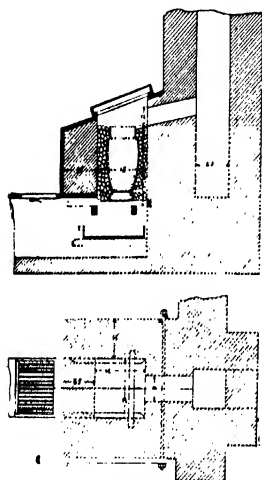


FIG. 3. COKE FIRED CRUCIBLE FURNACE.

PRESENT METHODS OF BURNING FUELS

should be openings to admit air to produce flame to play round the crucible.

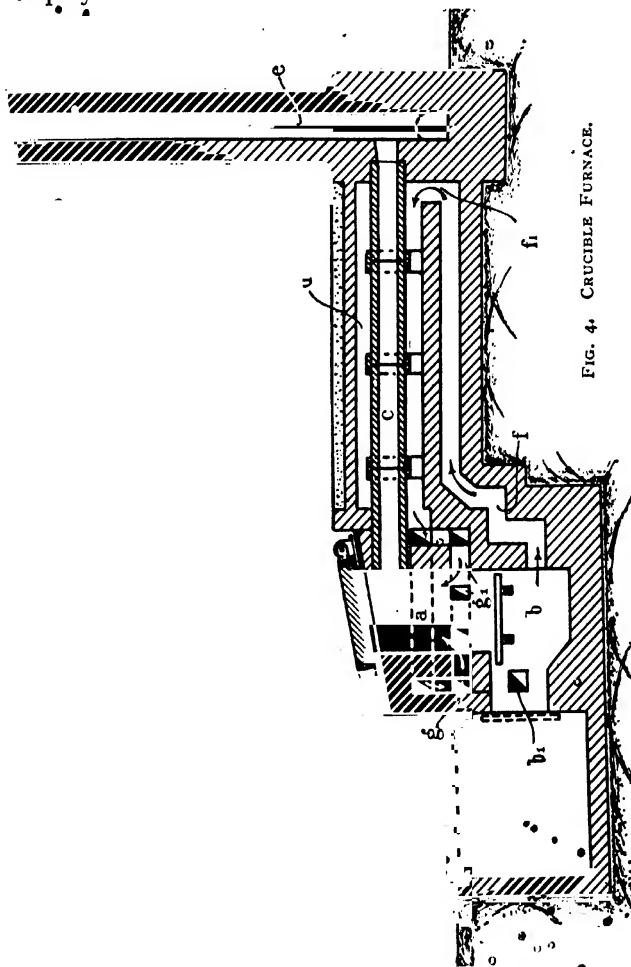


FIG. 4. CRUCIBLE FURNACE.

The loss due to the high temperature of the gases

SMOKE PREVENTION AND FUEL ECONOMY

from a furnace of the type of Fig. 3, as well as the loss due to the production of carbonic oxide, is avoided in the furnace (Fig. 4). Here air is admitted elsewhere than at the grate by lateral openings, which supply oxygen (air) nearer to the top of the fire in order to secure more perfect combustion.

The waste gases flow to the chimney by the flue C, around which the air is drawn as shown by the arrows, and delivered through the openings *g*, *g* and *a*, to the furnace. With this design there is less stoppage from clinker. The waste gases may also be employed to heat a second supply of metal prior to placing it in the crucible, as in the construction shown in Fig. 5. In this case the metal to be heated is placed

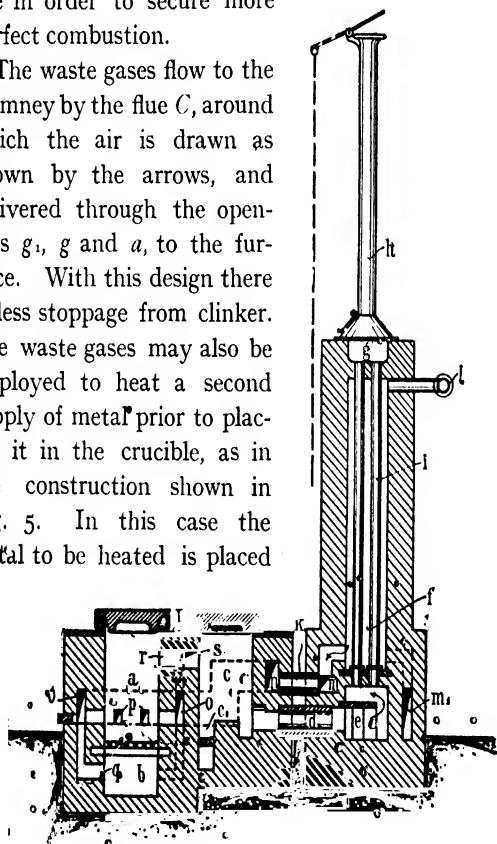


FIG. 5. CRUCIBLE FURNACE.

PRESENT METHODS OF BURNING FUELS

between the crucible chamber and the regenerative air heater as shown in Fig. 4, namely, in the second chamber *C* (Fig. 5). In this furnace *f* is the air heater supplying hot air to the primary furnace at *q*, *p*. The second furnace has a half grate *c*, and if necessary, metal can be melted as well as in the primary furnace. In burning coal, there may also be the above loss of effect through the production of carbonic oxide, but this is less likely to take place, because, the fire being thin, a surplus of air enters through the back grate.

A better idea of the whole problem may perhaps be gained by considering the course of events when coal is hand-fired by either of the usual methods of coking or spreading.

When the fire has burned down to the replenishing point the fire-door is opened and an enormous volume of cold air rushes in over the fire, cooling the whole of the boiler and its flues, tubes, brickwork, and also the economizer or feed heater, if this is present. This easy entrance of air obviously checks the entrance of air through the grate, where the resistance to its passage is always high.

The fireman now charges with about 56 pounds of fresh coal, which he places either wholly in front at the dead-plate, or spreads evenly over the surface of the red fire. In 56 pounds of coal there will be about 250 cubic feet of gas. This is rapidly distilled from the coal, especially when the spreading system of firing has been adopted. The volatilizing of solid fuel absorbs an enormous amount of heat,

SMOKE PREVENTION AND FUEL ECONOMY

cooling down the red fire.¹ Meantime the boiler itself continues to absorb heat, so that the green gases pass into the flues unburned, or they are only partially burned. Usually, the fire-door being open, the freshly produced gas ignites at once, for the first shovel of coal does not blank the whole of the red fire surface, and when the full charge of 56 pounds is complete there are huge volumes of flame pouring over the bridge. The door is then closed. The air supply being thus shut off and the fire choked with green coal, the flames are not supplied with oxygen through the grate, and become extinguished. The sudden cooling exercised on the heated gas by the boiler plates is said to split them up into lighter hydrocarbons and carbon. This free carbon is soot, which, floating in the stream of gas, produces black smoke. In black smoke there is not merely black carbon, but there is half-burned carbon in the shape of carbonic oxide. When the coking system is employed, the fire is burned through in patches. The distillation of gas is more prolonged, an excess of hot air is coming through the thin fire, and the gas mixes with this in its passage over the hot fire, and perfect combustion is more easily obtained.

The coked mass of fuel, when freed from its volatile gas, is pushed back over the fire by a rapid push of a wide rake, and a fresh charge is soon after put to coke upon the dead-plate. Wye Williams pointed out these things many years ago, and insisted on

¹ Vide *The Electrical Review*, Aug. 30, 19

PRESENT METHODS OF BURNING FUELS

the supply of air above the grate by means of openings in the fire-door which admit air through perforated plates in fine streams, so as the better to mingle with the gases.

A good fireman can use these door grids successfully. They should, however, be arranged to open automatically as the fire-door is closed after firing. They should then slowly open a little wider, and slowly close in about two minutes or so, as may be found necessary, thus regulating the supply of air to the output of gas. After all the volatile hydrocarbons have been driven off, the solid carbon on the grate will usually secure sufficient oxygen. About three or four square inches of air opening at the door is found necessary for each square foot of grate area. ..

The air may be admitted at the bridge, but in that case it loses the benefit of the heating effect of the fire, and of the better mixing effect. Effective mixture is of prime importance, as also is a sufficient temperature. This latter is the point at which the Lancashire boiler, with its water-arch furnace, is apt to fail.

In that class of water-tube boiler setting wherein the gases rise vertically from the fire, and pass to the tubes where they are promptly cooled below ignition point, the mixing action is seriously deficient, and this was attempted to be remedied by Belleville, who injected air at a high pressure horizontally over the fire surface, to whirl the gases and burn them before they rose between the tubes. The space for

SMOKE PREVENTION AND FUEL ECONOMY

this action, is, however, too limited for success to follow.

No doubt mixture is effected by the water tubes, and the gases will often ignite and burn uselessly beyond the boiler. In the sequel it will be seen how the various points above named have been more or less provided for. We would specially urge the important essentials of mixture and temperature. Practice has shown that unless there is a draught of at least half an inch of water gauge, the admission of air above the fire does not take place satisfactorily, and in such cases it is usual to aid its introduction by a steam jet, placed so as to point from above the door towards the middle of the length of the fire. Experience also shows, that it is easier to prevent smoke by first admitting too much air at the door, and closing rapidly, than by admitting too small a quantity. If too little air is initially admitted, the gases do not burn freely, and soot is produced with less temperature, and it is difficult to re-establish perfect combustion. By admitting an ample volume of air at first, and putting the gases into active combustion, there is at once produced a high temperature, and the door grids may be sooner closed, for combustion will continue with a less excess of air above the chemical minimum.

It will be apparent from the foregoing, that the difficulty in burning bituminous fuel lies in the fact that it is a complex substance, and burns partly as a solid and partly as a gas. The gas must be burned in a time much shorter than is necessary to burn

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the solids. The régime of the furnace is constantly changing. The fire is cooled during volatilization of the gas. Hence the dictum "little and often," as applied to the firing process, so as to reduce fluctuations to a minimum. But this implies many more openings of the furnace door, and has only been carried into practice by the processes of mechanical stoking. The machines for this provide a continuous feed of coal, either by the coking process, or by the

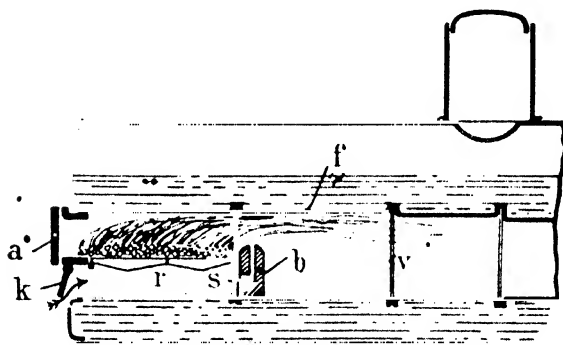


FIG. 6. ORDINARY FURNACE OF CORNISH BOILER.

process of sprinkling. The evolution of gas is thereby evenly distributed. The régime of the fire is more constant, and the supply of air, once found best, can be adhered to as closely as atmospheric changes will permit.

The régime is less regular than it would be did coal not contain dirt to form clinker to choke the grate. Hence the use of moving bars, which tend more or less to be self-cleansing.

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In Fig. 6 is shown a usual form of furnace of the Lancashire, or Cornish, or similar type of boiler. Here *a* is the door, *b* is the bridge, shown with an air passage in place of the door being perforated. *S* is a damper to regulate air admission through *b*. An ashpit damper *k* controls the air admitted below the grate, and, incidentally, through *b*. It is often necessary to limit the air flowing through the grate, in order to assist its entrance above the fire. But in this design the damper *k* cannot be used to do this, without at the same time controlling the air supply through *b*. For this reason, apart from other reasons, the secondary air supply is better effected through the door *a*, than through *b*. The damper *k* then affords a powerful means of controlling the supply of air to the furnace, both below as well as above the grate.

The Westphalian coal of Germany contains 4 per cent. of tars, 4 per cent. of gas water, and 16 per cent. (equal to 30 cubic metres per 100 kilos of coal) of gases; in all, 25 per cent. of volatile matter. Many English coals contain 35 to 37 per cent. of volatile matter. A study of the above type shows that the following conditions must be fulfilled, as already pointed out in general terms.

1. A temperature above $700^{\circ}\text{C.} = 1292^{\circ}\text{F.}$ in the furnace, and no contact of the hot gases with the colder walls of the furnace, until combustion is complete.

2. A sufficiency of oxygen in the combustion space, preferably in a hot state.

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3. Skilful firing of the raw fuel evenly over the fire surface.

The first condition may be secured by the arrangement shown in Figs. 7 and 8, which consists in lining the furnace with firebrick internally. This prevents serious abstraction of heat from the fire, and secures so high a temperature that the gases will burn if only supplied with oxygen as per condition 2. Most patented devices provide for such air admission

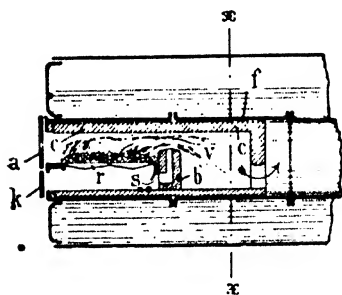


FIG. 7.

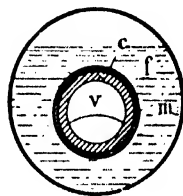


FIG.

REFRACTORY FURNACE FOR CORNISH BOILER.

at the bridge, and others provide for its admission at the door, which we prefer, but very few seem to consider the essential feature of temperature at the place of mixture.

In Fig. 7 this is provided for, by extending the firebrick lining, as shown. With bridge admission this extension will probably be greater than with door admission. The amount of secondary air thus admitted should be kept down as nearly as possible to the theoretical or chemical minimum, or the

SMOKE PREVENTION AND FUEL ECONOMY

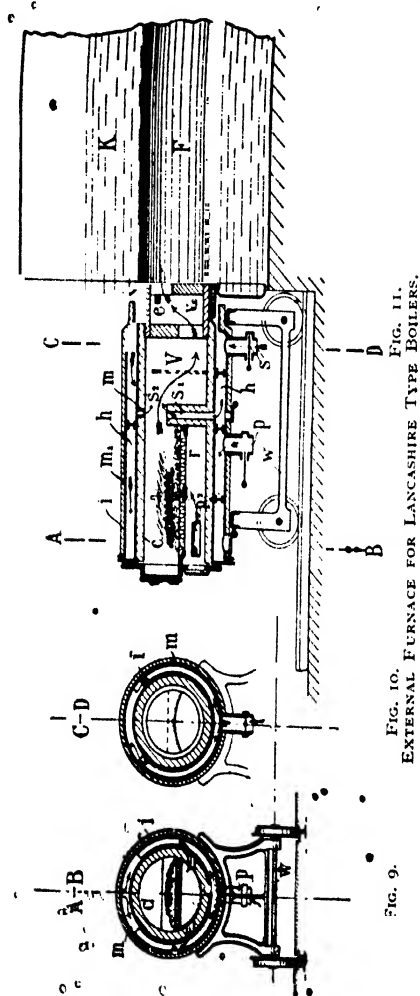


FIG. 10. FIG. 11.
EXTERNAL FURNACE FOR LANCASHIRE TYPE BOILERS.

cooling effect will be excessive. It is because so many devices admit too much air that they do not prove economical.

PRESENT METHODS OF BURNING FUELS

The firebrick lining, however, very seriously diminishes the size of the furnace, and the lining is not free from cost of maintenance. Hence the external furnace of Figs. 9, 10 and 11. Here the whole furnace is carried on a wheeled frame or platform. The furnace is enclosed in an outer case *i*. A split bridge *S*, admits secondary air from the external space *h*, through which further secondary air is admitted at *S*, above the bridge. Air is admitted below the grate through passages *p*, also in communication with the space *h*, which is supplied through the valves *p* and *S*.

Combustion of the gas takes place in the space *V* and beyond, the whole furnace being lined with firebrick as at *C*; no extension of the lining is necessary in the actual boiler tube *F*. The heat radiated from the furnace is partially taken up by the air which flows through the space *h*. The length is two metres and the diameter half a metre, the grate area $1\frac{1}{2} \times \frac{1}{2}$ m. = 8 square feet.

For English boilers, the fire-grate area would be larger than stated above, because the furnace tubes have a larger diameter than appears usual in Germany. Thus for boilers of 7ft., 7ft. 6in. and 8ft. internal diameter, the furnace tubes are made 33, 36, and 38 to 39 inches diameter, respectively, and the length of the grate is made usually 6ft. for hand firing. It is possible to maintain these widths with external furnaces, and it should not be impossible to employ a single breadth grate in the external furnace of a Lancashire boiler, so securing

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a grate of six to seven feet in breadth, if the thrust of the arch can be properly taken up.

Earlier attempts to secure the results possible with external furnaces have failed, from too great massiveness, and want of means for preventing great loss by radiation. With the furnace illustrated, these losses are much reduced by the air passing through the space between the casing and the furnace. Where there is as usual a spare boiler, the furnace may be wheeled from any boiler, which is to be laid off for cleaning or repair, to the spare boiler which is to be freshly started. This would help to reduce loss of heat stored in the furnace, which is estimated at 8.6 kilos of coal. This loss may be calculated, if the mean temperature of the mass of the furnace be known, the specific heat of firebrick being about 0.2. It has been argued that external furnaces are not economical, that steam cannot be raised with economy unless the boiler is exposed to the direct radiation of the furnace, and that with external fires this radiant heat disappears in some mysterious manner, being incapable of discovery either in the form of water evaporated, or of heat in the waste gases, and that in fact no one knows what does become of it. This explanation is unsatisfactory and improbable. It is doubtful if any satisfactory proof can be afforded of its truth, and grave doubts are thrown on the claim by Mr. F. Grover, who informs us that the smokeless combustion of Indian coal in such furnaces, appears to have been also coincident with a marked

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economy. A similar principle is carried out with water-tube boilers, by the construction of the furnace shown in Figs. 12 and 13. K and K_1 are a pair of

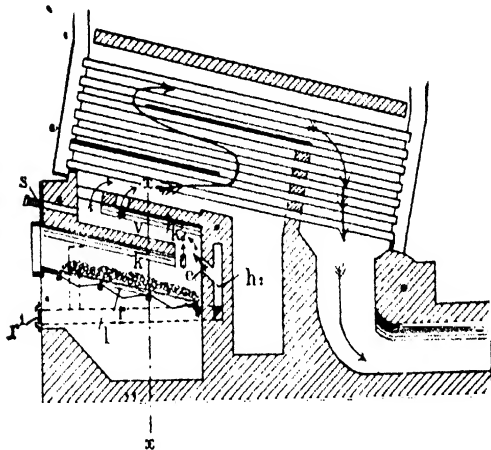


FIG. 12.

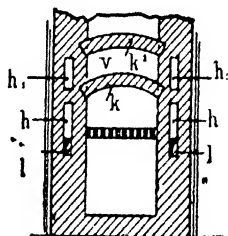


FIG. 13.

* BRICK FURNACE OF WATER-TUBE BOILERS.

firebrick arches thrown across the fire, so as to form an extended furnace and combustion chamber, in which combustion may be completed by aid of the secondary air, drawn through the hollow walls

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$h_1 h_2$ to the bridge wall at e . The volume of this air can be controlled by the damper r^1 .

Sight holes at S , and if possible through the side walls near the bridge, are provided. The upper arch may be perforated as shown. There is always more or less trouble with these arches in ordinary practice, because they are built with far too little care and forethought. Mr. Page, of Stourbridge, says that for sound work a fire block must not be machine pressed from a lump of clay. This is apt to cause planes of internal shear at which failure may occur. All specially stressed brick must be hand pugged into its moulds and should be burned at a temperature exceeding that at which it will be used. Bricks ought to be absolutely dried before going into work, and a new arch must be slowly warmed up. Its face may be smeared with a less refractory cement which will run, and set the arch face into a solid mass; this will minimize the common danger of the bricks splintering off at the first severe heat. The electric furnace product, *Siloxicon*, might be employed for this purpose.

A well-built arch of good bricks should last a year.

In such a furnace as this, the gases are compelled to travel over the full length of both arches, before coming into contact with the water tubes. As in other cases, the secondary air can be admitted—probably with advantage—at the furnace door.

The whole boiler must stand higher than when it is set in the usual manner; but the usual manner of setting a water-tube boiler is so barbarous and

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unscientific that it does not merit a moment's consideration.

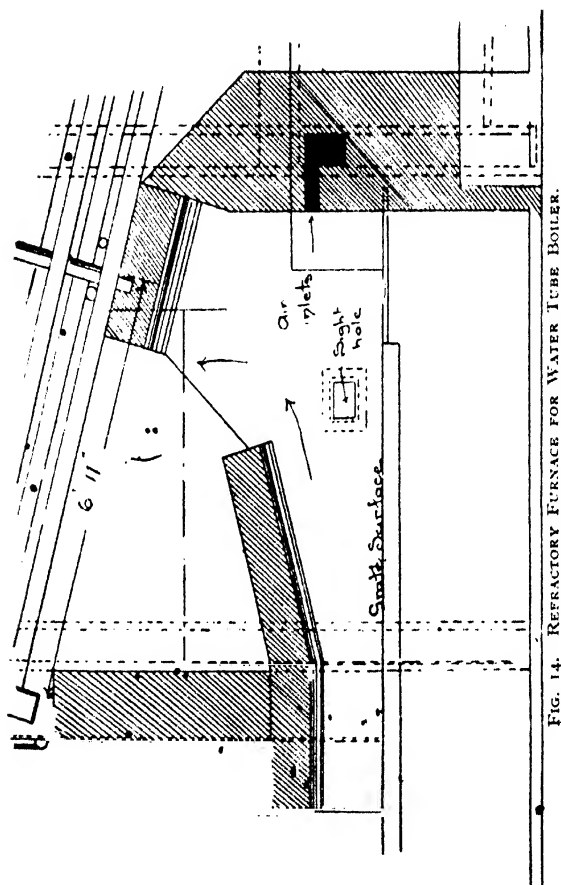


FIG. 14. REFRACTORY FURNACE FOR WATER TUBE BOILER.

It is, however, to be said that even better results can be obtained by an extension of the principle

SMOKE PREVENTION AND FUEL ECONOMY

of Fig. 12, that is, by raising the boiler even higher, and considerably enlarging the combustion chamber, as in Fig. 14.

It is unfortunate that so little attention has been paid to the art of stoking. This has been too much considered as only an unskilled labourer's work, whereas it involves the economical conversion of valuable coal into heat, and a fireman's wages are but a small proportion of the total cost. In a week of 56 hours a high class fireman has been known to fire 80 tons of coal, but 50 is a good week's work. He may thus be handling twenty to thirty times the value of his wages, and a difference in skill that will save only three per cent. of the fuel, may well be worth an addition to his pay of one-half. A good man can, under fair conditions, fire Lancashire type boilers without smoke and with economy. The furnace of such a boiler is in fact near the critical point, and it will smoke on slight cause. Smoke prevention apparatus should be of such a nature as to widen out the critical margin, by improving or insuring the necessary conditions, without introducing uneconomical fads such as excessive air.

All apparatus should aim to reduce the air supply to a chemical minimum. This will always be possible in a refractory furnace of sufficient length, because the mixture of air must be complete in time, and combustion will go on, so long as there are no serious cooling effects. Practical success is secured where, without excessive combustion space, and with an excessive

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cent. above the theoretical, there is no smoke, but a light occasional haze. In hand firing, as already seen, coal is applied either by spreading or by coking. The spreading system is variously modified. Coal is fired over either the whole fire area at once, or it is fired over the front and back ends alternately, the object in each case being to preserve a red fire over half the area, in order to supply part

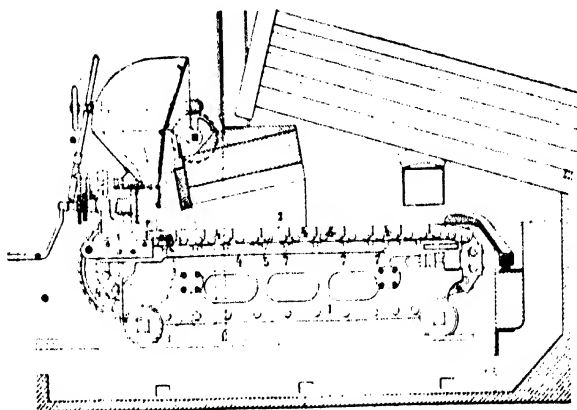


FIG. 15. THE CHAIN-GRATE MECHANICAL STOKER.

of the secondary air to the gases from the other half, and to keep up the temperature.

In stoking by machinery, these various methods are all more or less approximated. A perfect mechanical stoker is not known, but a fair amount of success is secured by them, and they cannot be regarded as altogether unsatisfactory.

One of the oldest forms of mechanical stoker is that illustrated in Figs. 15 and 16. It has lately

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come again into prominence as a stoker for water-tube boilers, but its inventor was one Juckes; and it was at one time extensively employed in Yorkshire for under-fired Lancashire boilers, practically as shown in Fig. 15, but sometimes with the chain grate brought much further forward, so as to provide a considerable additional length, on which coal was hand distributed. This coal passed under the edge of an adjustable vertical plate, which levelled it to an even thickness. It then passed slowly under the arch of firebrick which protected the front lower end of the boiler, gradually becoming coked as the moving chain grate carried it to the bridge. Secondary air was admitted by leakage through the green coal under the "doctor" plate, and through the bridge-end of the fire where burned thin.

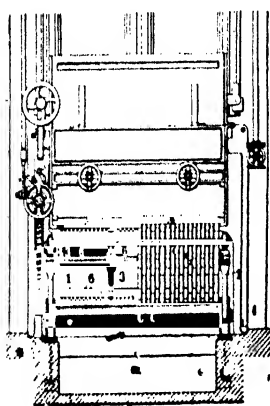


FIG. 16. THE CHAIN-GRATE
MECHANICAL STOKER.

The difficulty then, as now was, that the burned out fire admitted too much air. The furnace was intensely hot, and the under-firing of large shell boilers not being approved by Boiler Insurers, the Juckes furnace fell into disuse with the system, until it was resuscitated for water-tube boilers.

The chain-grate furnace is always clean, and it was fairly smokeless

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under the shell boiler, but of course it must fail under the straight ascending flow of the usual setting of the water-tube boiler. It will work smokelessly with a setting such as that of Fig. 12, and is practically perfect when arranged as in Fig. 14, which is the arrangement employed by Mr. Miller, of the Kensington and Notting Hill Electric Light Station.

The thickness of the fire at the bridge end is kept up by means of the bridge plate, which allows the advancing fire to heap up, and the surplus falls over into the pit beyond, where it can burn out. The bridge plate must be hollow, and cooled by a constant flow of water, or it will rapidly burn out. These grates sometimes give trouble by bending, and by failure of the link pins. Mr. Miller discards pins, and casts bosses and recesses on the links themselves, which are so shaped as to avoid the wide air gaps, at the bending of the chain round the end rollers. In this form of chain, each line of links is longitudinally independent.

The chief fault of the chain grate is that enormously excessive volumes of air are admitted through the back ends of the grates where the fuel has burned wholly or nearly away. This has been remedied by the use of open top boxes laid close beneath the grate so as to shut off the air, as arranged by Eckley B. Cox. The system suggested by W. H. Booth was a series of shutter plates so hinged and provided with pull rods and cranks as to allow the plates to be adjusted more or less

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inclined to admit the volume of air required by the amount of fuel still remaining on the grate. See p. 195 for description of how this has been carried out by the Babcock & Wilcox, Co.

HAND FIRING

While hand firing possesses the advantage that it may be done by an intelligent man, it has the objection that, while firing is in operation, great volumes of cold air are rushing in at the door. Hence such patents as Fig. 62, where the attempt is made to get rid of part of this objection. Mechanical stoking does avoid this difficulty, but these machines have their troubles also. Excepting the chain grate, the ordinary moving bar of the mechanical stoker requires to be cleaned at intervals. To do this, the hopper feed is stopped, and the grate burned bare, the dampers being gradually closed as the fuel burns off, and completely closed during cleaning. When clean, the feed is restarted, the coal first fed will often be ignited by previous backward burning and will at once flame. If the draught is good the coal will burn very fiercely, and it requires a long time to get the grate fully covered again, during which time cold air is rushing freely through the bare grate, and diminishing the duty and efficiency of the boiler and of the economizer also. If to check this, the boiler dampers are closed, there will be too small a volume of air drawn in above the fire to burn the gases, and black smoke will be

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made. In such a case, a damper may be placed under the grate, so as to shut off air from the rear of the grate, without diminishing the air supply above it. In this way the gases receive the air necessary to burn them, and the fuel on the grate burns slowly. When the fuel has travelled as far as the bridge, the ashpit dampers are again opened, and regular working is resumed. This ashpit damper is also a useful appliance for a hand-fired boiler, for it enables the draught to be regulated so as to give the desired intensity of combustion, without diminishing the draught above the fire, the full chimney draught being available to draw in air to burn the evolved gases. Without this aid smoke will often be produced, especially when the grate surface is too large and the chimney damper is kept too much closed in order to check the combustion. Thus in the absence of an ashpit damper smoke may be prevented or reduced if the firegrate is made smaller and the chimney damper kept wider open as will then be necessary (see p. 90).

BROADBENT'S APPARATUS

An appliance to regulate air admission is that of Broadbent, which consists of a set of louvres in the furnace door. These are all joined to a middle vertical bar, which serves as the weight for a piece of clockwork. This clockwork has a springless, heavy escapement wheel, like a fourteenth-century clock, which oscillates under the pull of the weight,

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and allows this to run down. The clock is connected by a chain to the louvre weight, so that when the furnace door opens, the lever on the clock falls back over a ratchet wheel, and when the door is closed, the ratchet holds back the lever, and the louvres are fully opened to admit the maximum air supply over the fire. The escapement of the clockwork then begins to move, and allows the louvres to shut in about two-and-a-half to three minutes, after which time there is no further hydrocarbon gas to distil off the last charge of fuel. The process is then repeated at each charge of fuel. Similar results were aimed at by means of door louvres, hung to a ratcheted lever on a shaft overhead, which slowly revolved and let down the louvres at a fixed rate.

Oil cataracts also are employed for the same purpose, and in skilled hands these various appliances serve the purpose of admitting air when needed, without allowing it to continue too long. With means for ensuring sufficient temperature, they would undoubtedly be very good smoke preventers.

UNDER FIRING

Great store has been set on the idea of feeding coal from below the fire, so that the green coal should give off its gases below the red coked fuel above, which will thus heat the gas, and assist it to burn.

This end has been variously attained. One such

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device is seen in Fig. 76, German Patent No. 123,300, described on page 211. Many years ago, Mr. Holroyd Smith introduced coal to the furnace by means of long helices, which carried the coal along longitudinal troughs in the grate surface. The gradually reducing size of the helices, and of the troughs, compelled the coal to escape upwards. The principle of under firing has not come much to the front as regards English inventions.

The Hopcraft furnace, which came out with such a flourish in 1889, had a circular revolving grate, inclined at an angle of 25° . Coal was fed through a central pipe, round which the grate revolved, by means of a jointed series of flights or short helices. The revolution of the grate set up a weak line in the fire, at the circumference of the circular part, and the draught, which was by fan, spent its energy round this weakened channel, which it blew into a state of brilliant incandescence, the rest of the fire remaining dull and dead. The furnace proved a complete failure; and the under-feed system has not met with much success until recently, when certain American under-feed furnaces have been introduced. These possess the novel feature of a grate inclined downwards from the fuel supply trough, with a modification of the step grate placed across the furnace. An example of this grate will be found in the section dealing with American Patents.

In the Vicars stoker, short straight bars are employed, which have a forward movement all at one time, but a return movement which takes place at

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two distinct times, all the alternate bars first moving back, followed by the remainder. The net effect is to carry the fire forward. The bars receive their fuel from a hopper, out of which it falls in front of a pair of wide reciprocating plungers. These thrust it forward upon the bars, where it becomes coked as it moves forward under the firebrick arch, and gradually burns off towards the bridge. The still unconsumed fuel falls over the bridge into the hollow beyond, and is burned out, the ash and clinker being cleared from under the grate, and falling preferably down the hopper ashpit to a conveyor below.

The firebrick arch occupies a considerable length, and combustion is fairly smokeless. A high percentage of CO₂ can be secured by this stoker.

Objection is raised to stokers of the sprinkling order, that the dust of the coal is carried by the draught into the flues, and even out of the chimney top. Either by damping the coal, or by providing suitable chambers for the dust, this may be prevented, but damping cannot be recommended, for the reasons given on pp. 150, 151, Chapter IV.

The sprinkling mechanism is various. Some stokers throw their coal, by dumping it in small quantities in front of spring actuated shovels, which throw the coal over a limited area of the furnace at each throw. The severity of the throw is varied by the action allowed to the spring, and thus the whole fire surface receives its share of fuel, which is spread by the bottom of the throw chamber or

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by experimentally determined semi-obstacles. Other sprinklers consist of rapidly revolving wheels or fans, upon which the coal is dropped from the hoppers. These wheels revolve on a vertical axis, or they may revolve on a horizontal axis.

In the stoker of the E. S. E. Stoker Co., of Blackburn, the sprinkling is alternately along the sides of the fire, so as to resemble side firing by hand (see p. 201).

In all, it will be observed that fuel is supplied continuously, and maintains a constant condition of the furnace. Such smoke as is made is steady in amount, and constant, and though it is maintained at a density less than what may be called the "prosecution blackness," nevertheless its daily volume is sometimes considerable, and mechanical stoking cannot be considered by itself as a smoke preventer. It must be employed with the same precautions as are necessary with hand firing.

Anthracite coal cannot easily be stoked by any system of coking, and it must be kept quiet during burning. It is therefore not suitable for firing by mechanical stokers of the coking type. Nor does it require secondary air to burn off volatile gases. Anthracite must, however, have a secondary air supply, to burn the carbonic oxide (CO), if the fire is too thick to allow an excess of air to pass through it. With bituminous coal, only from a fourth to a half of the total heat is actually set free at the grate. Considerable heat is absorbed in volatilizing the solid coal, and the gases which absorb this heat pass

SMOKE PREVENTION AND FUEL ECONOMY

off and burn in the upper part of the furnace, or beyond it, so that the firegrate is not exposed to very severe heat. Anthracite coal burns almost wholly at the grate surface, and the temperature produced is high. Any slightly projecting bar will melt off, and there is usually considerable trouble with the grate. Special grates for anthracite consist of flat plates, pierced with holes. Round each hole, the plate rises up in the form of a low hill, and the area between the hill tops, which are perhaps a quarter of an inch high, becomes covered with ashes which protect the plate surface.

Summarizing the whole question of mechanical stoking, it may be pointed out how very much better fitted for perfect combustion is the under-fired boiler, than the internally-fired boiler, owing to the large space available for the grates. One of the greatest enemies to economy is the creation of bare patches in the fire. This we have seen is the cause of trouble with chain grates. Certain machine stokers minimize the trouble, by using short bars, and by dumping the still unconsumed fuel, into a back pit, where it can burn out to a finish. But in the inclined grate, the aid of gravity is called in, so to agitate the fire, which packs downwards automatically, and closes up its hollow parts by drawing upon the thicker bed of fuel at the upper end of the grate. These grates are so arranged that the fire is approximately self-regulating in thickness, for as it packs downwards, it becomes self-supporting, and ceases to move down hill so very rapidly. It is difficult

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to imagine anything much better than the inclined step grate, but it requires to be allowed for in original construction. It should always be combined with the over arch of firebrick, and with the general arrangement of furnace and direction of flow of gases, which have been already pointed out as essential for obtaining a good mixture and sufficiently high temperature.

It is also claimed that every coal requires a special angle of inclination of the stepped grate if the best results are to be secured. To effect this the grate may be arranged so as to be adjustable to the necessary angle. This angle is of course such that the fuel packs downward at the proper rate to make up for the part consumed. A dump plate at the foot of the grate is necessary for the purpose of getting rid of the gradually accumulating mass of ash and clinker. Such dump plates may be double, being withdrawn alternately from beneath the ashes which are discharged at each operation by the amount that can be held between the two dump plates (see Fig. 18).

Gravity grates fail when their angle is too flat for the quality of the fuel. Coals of the coking variety will sometimes hang upon the bars. Hence the advisability of a variable angle to suit changes of fuel.

CHAPTER III

Improved Methods of Burning Fuel

STEP GRATES AND GAS FIRING

STEPPED grates have been little used in Great Britain, simply because under-fired boilers have gone out of favour. A step or an inclined grate affords the simplest means of moving the fuel along the grate as combustion proceeds, thereby closing up voids and preventing excessive admission of air. When the angle is properly chosen (it ought to be adjustable) an even and uniform bed of fire can be obtained by this method of construction.

Two forms of inclined grate are in use in Germany and on the Continent. In one, the grate is of the usual form with straight bars, but it is inclined at a steep angle as in Fig. 17. This still retains the disadvantage, that fine coal and dust easily fall through the bars. Coal of strongly coking property, or which produces much clinker, is also not found satisfactory on such a grate.

In the true step grate, as in Fig. 18, plates are arranged as in a staircase, but the risers are omitted, and the openings thus made afford access for air.

IMPROVED METHODS OF BURNING FUEL

This form answers admirably for fine coals, lignite, peat, and tan bark, or sawdust, which cannot be burned advantageously on ordinary grates.

In Fig. 17 the simple inclined grate is shown fed from a hopper *t*, ash and clinker collect on the little bars, *p*, and secondary air is admitted at *l*, through

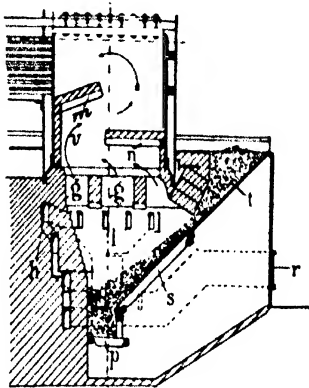


FIG. 17. INCLINED GRATE.

lateral passages *h* controlled by a damper *r*. The gases thence proceed to the boiler, which in this case is seen to be of locomotive type, with two brick arches, *m* and *n*, to divert and mix the gases, and diffuse them over the volume of the dome of the combustion box before they escape to the tubes.

The step grate of Fig. 18 is shown, applied to a somewhat similar furnace, in advance of a flue tube boiler. Coal supply from a hopper is regulated by a doctor plate *b*, secondary air is admitted at *l*, *l*₁, and regulated by a damper *r*, which controls the heating rays *h*, *h*₁.

Ash and clinker are deposited on the lower shutter *p*, and may be let down upon *p*₁ by withdrawing *p*. On replacing *p*, the lower shutter *p*₁ being drawn out, deposits the intercepted ash and clinker in the ashpit. The fire can be held down by a

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rake, through the opening *k*. If, however, the fuel be of suitable quality, the fire will slide down the grate, when the support at the foot is removed by each cut out of ashes when the shutters *p*, *p*₁ are used.

To note the perfection of combustion, a sight

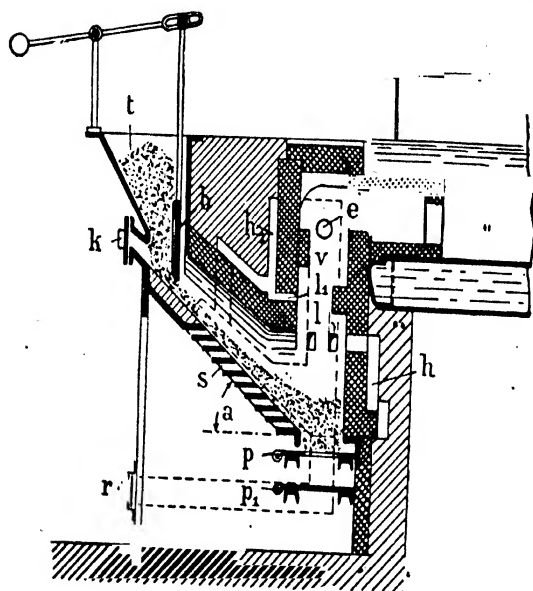


FIG. 18. STEPPED GRATE.

hole, *e* is provided in the side wall. The products of combustion are finally passed into the boiler flue. Grates of the form of Figs. 17 and 18 are usually inclined at an angle of 45°, those of Fig. 18 being at about 35°. These inclined grates, with brick combustion chambers, are, in a sense, a sort

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of half-way house on the road to gas firing. When the grate is very steeply inclined, there are few voids in the fire. Much carbon oxide is produced, and unburned hydrocarbons are given off from the thick mass of fuel. As both the fire thickness and the secondary air supply are controllable, the combustion ought to be perfect and smokeless. The heating of the incoming air by the walls also makes for economy. This half-gas firing is not sharply differentiated from other methods of firing, but there is a gradual transition from the ordinary plain furnace to the actual gas producer, and no attempt need be made to define the limits. Thus it would be difficult to say whether the reverberatory furnace of Fig. 19 belongs to the gas-fired

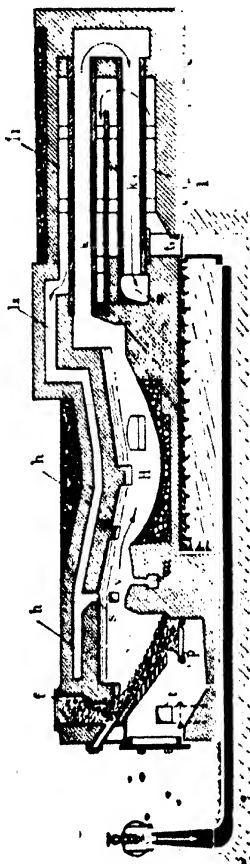


FIG. 19. REVERBERATORY FURNACE.

SMOKE PREVENTION AND FUEL ECONOMY

type of to the solid-fired type. Hence the term "half-gas firing." But all the heat of the fuel goes to the furnace, which in this case is shown with a steam impelled secondary supply of regeneratively heated air, which traverses the passages z^1 heated by the

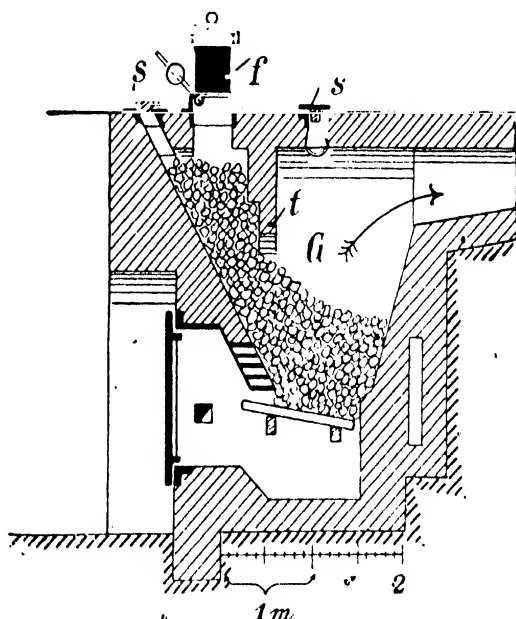


FIG. 20. GAS GENERATOR, ORDINARY TYPE.

flues k , k_1 and enters the furnace at S and m to complete the combustion prior to the arrival of the gases at the hearth H of the smelter. The air, even though hot, is less heavy than the gases, and is thought to mix better when forced in above these at the top of the combustion chamber V . Careful

IMPROVED METHODS OF BURNING FUEL

regulation is necessary, which is effected by the damper *t*.

The use of forced draught, or compressed air,

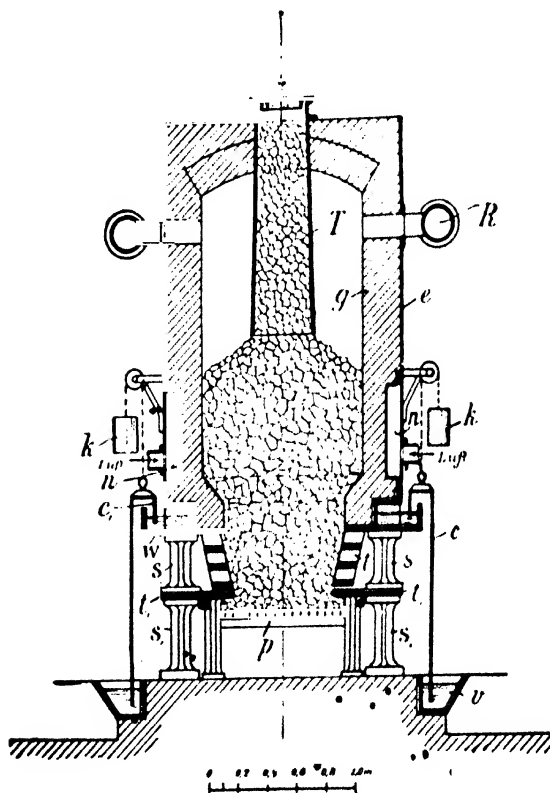


FIG. 21. CENTRE-FEED GAS GENERATOR.

offers advantages which have not yet been fully grasped by engineers.

A gas generator of ordinary type is shown in

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Fig. 20. It does not differ widely from Fig. 19. The fire is thicker, 60 cm. to 1 m. = 24 to 40 inches. This thickness is obtained by using a steeply inclined front to the furnace. There is a hanging bridge *t*, which performs the important function of maintaining a uniform thickness of fire upon the grate. This is an important and essential requisite for gas generation, as it preserves the uniform régime of the furnace and a constant quality of gas. Openings for fire-irons are provided at *S S*, for use if necessary in regulating the fuel.

The constant fire thickness is secured in another type of gas generator by the charging shaft *T* of Fig. 21. Since with the same fuel, a gas generator, properly regulated, should always produce a uniform quality of gas, the problem of perfect combustion is much simplified and resolves into supplying the necessary air for secondary combustion. The fuel on the grate is burned at once to carbon dioxide (CO_2), but this is all converted to carbonic oxide (CO) in its passage through the thick bed of fuel. An essential condition of the use of gas producers is that the work shall be continuous. If this condition is fulfilled, their use leads to economy without smoke.

In Fig. 22 is shown an application of a gas generator to the firing of a boiler. The generator and the boiler here shown are one of a series, arranged in parallel on a common gas flue *H*. The boilers are of Lancashire or Cornish type. In front of each tube is a gas combustion chamber *V*, *V*₁, *V*₂.

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Air is supplied through a main S through branch

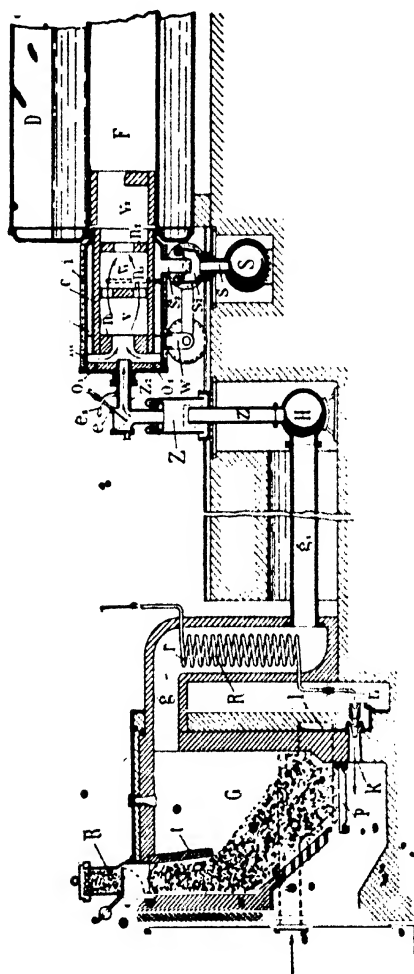


FIG. 22. BOILER FIRED BY GAS GENERATOR.

pipes, S_1 , S_2 , to the individual combustion cham-

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bers. At *R* is a coil, to superheat the steam supplied to the generator through the blower *L*, which induces an air flow under the grate. This air

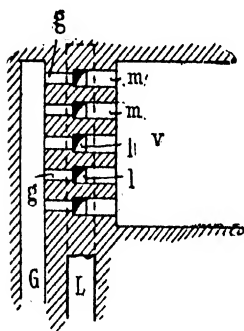


FIG. 23.

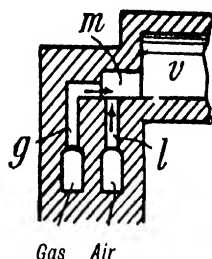


FIG. 24.

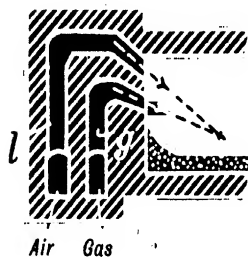


FIG. 26.

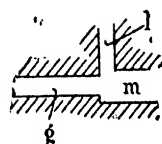


FIG. 25.

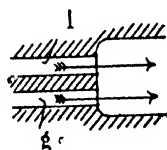


FIG. 27.

is heated in the wall channels, *L*. Water gas is thus produced to some extent. It leaves the generator at a temperature of 600°C. (1112°F.), and some of this heat is saved in the steam coil *R*. The gas passes through a pipe *g*, to the water-sealed

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bell Z , and thence to the chamber V , through a Regulator e . Air is admitted at o , o_1 , and thorough mixture is secured by means of the baffles y , n_1 , n_2 . This air is heated in the space between the combustion chambers and the outer casing. The combustion chamber is mounted on a carriage, and the bell Z being raised, severs the one joint between the gas producer and the furnace. Another bell at S , serves to disjoint the secondary air main.

An important feature of all gas-firing systems is the ease with which the secondary air can be heated, and if done with otherwise wasted heat, the economy is obvious. The question of mixture of the gas and air is however not given the attention it deserves.

If a wide hearth is to be gas fired, the air and gas must be divided into several streams, as in Fig. 23, where g , g , are the gas openings, and l , l are secondary air ducts, delivering preferably above the gas supply, as shown in Figs. 25, 26, 27, rather than as shown in Fig. 24; since the mixing is more rapid and perfect when the air comes from above the gas.

For a short hearth the arrangement of Fig. 25 is recommended. For longer hearths Fig. 26 may be used. A very long flame may be obtained by parallel flow of air and gas which retards the mixing, as compared with the impinging effect of Fig. 26.

When, however, a reducing effect is required, the air should be brought in below the gas. This retards the complete combustion, and secures the reducing effect sought for.

SMOKE PREVENTION AND FUEL ECONOMY

DUST FIRING

Perhaps the most perfect system of burning coal is to reduce it to a fine dust, and blow it into a brick-lined furnace, by aid of the air required to burn it. Thus applied, coal dust burns like gas, with a hot and fairly short flame, the rapidity of combustion varying with the fineness of the dust. The worst and most violent coal pit explosions are those in which the dust laden air becomes fired. The dust may be thrown into the air by a small gas explosion. The dust of bituminous coal is very readily ignited and burns with great rapidity and violence. Dust is of course fed in a small stream into a furnace, and being mixed with the air supply it burns with a steady rapid flame like so much gas. So applied, coal should of course be freshly ground. The objection to dust firing is, that the fine ash or incombustible portion of the coal, is carried forward with the waste gases and out at the chimney top, thus becoming a public nuisance. A remedy for this could probably be found in a circular depositing or whirling chamber, "or stive" room, in which the gases would part with their load of dust. The cost of grinding is an item of some expense, that should however be partly covered by the cheapness of the coal, which may be the finest slack. It ought also to be possible, to suit the air supply very closely to the chemical minimum.

Satisfactorily to use dust coal it is said that it must contain not less than 15 per cent. of volatile

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hydrocarbons. It would appear that the flame is really a hydrocarbon gas flame in which the extremely fine particles of solid carbon are highly heated and caused to burn rapidly.

In order to grind coal efficiently, it must first be dried. It is stated by Mr. C. O. Bartlett that twice the quantity can be ground when the moisture is reduced to 1 per cent. than can be ground when it is left at 2 per cent. Not more than six or eight pounds of moisture can usually be dried out per pound of fuel burned, and it is not advisable to deliver the dried coal above 150°F. Of course the fuel spent in drying should save some of that necessary in the steam boiler, when coal is burned undried. The same engineer thinks that coal will in time all be burned as dust, but fully recognizes the dust problem, and the necessity for catching it. The system of coal-dust firing seems to the Authors to be sound in principle, if only it can be successfully applied. The prevention of the nuisance of fine ash produced in the flues and spread over the surrounding property is, however, essential to such successful application.

An excellent system of coal grinding appears to be one in which the coal is passed through a "Devil" disintegrator which blows the dust into a room the walls of which consist of teased cotton cloth, a species of stout flannelette. This allows the air to escape freely while effectually preventing the escape of even the very finest dust.

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LIQUID FUEL¹

Liquid fuel may be almost classed with dust coal. It is fired by first heating it to render it as limpid as possible, after which it is blown from an injector or atomizer by means of air, preferably hot, at not less than 20 pounds pressure, or by steam, preferably superheated. Liquid fuel is burned either alone or in combination with solid fuel. As with solid fuel, it must be well mixed with air, and the temperature must be well preserved until combustion is completed; to which end furnaces are more or less lined with firebrick. It is easier to burn liquid fuel with a small excess of air, than it is to burn solid fuel. It is free from the objection of dust, which applies to dust fuel, and would become a very general fuel if its production could be increased.

It may be noted here, that high temperature is promoted by perfect air mixture, because of the more rapid combustion—and perfect combustion tends to shortness of flame. Hence good conditions act and react on each other to produce the best results—for when the flame is short there is less risk of premature cooling by the boiler plates, and there is less need for long extended firebrick lining, and therefore a longer path for the gases in contact with the boiler plates.

In Fig. 28 is shown the liquid fuel atomizer by M. Guyot, as used in certain tests at Indret, of the French torpedo-boat boiler, Fig. 29. From these

¹ See *Liquid Fuel and its Combustion*. W. H. Booth. Constable & Co.

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figures will be seen how the furnace is lined with firebrick, to conserve the temperature of the burning oil, and also a usual arrangement of air atomizer, showing the oil and steam passages. These atomizers are all much alike in form, and differ only according to the ideas of their designers, as to the best degree of atomization that can be secured.

Liquid fuel burners are also made which are

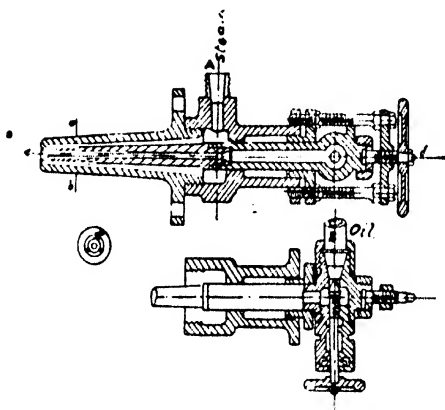


FIG. 28. GUYOT LIQUID FUEL ATOMIZER.

fed with filtered oil at a high pressure produced by a pump. The oil is forced through a small hole after passing by an obstructing spiral or screwed tapering spindle. This gives the stream of oil a whirling motion causing it to balloon out as it leaves the nozzle and produce a wide spreading flame. The admixture of air is also much facilitated by this action. Körtings burner is constructed on this principle. Where natural gas is available

SMOKE PREVENTION AND FUEL ECONOMY

at considerable pressure it has been employed as the atomizing agent, affording itself an addition to the fuel. Openings must be provided for the entry of air the flow of which is caused by the inductive effect of the gas or steam used as the atomizing

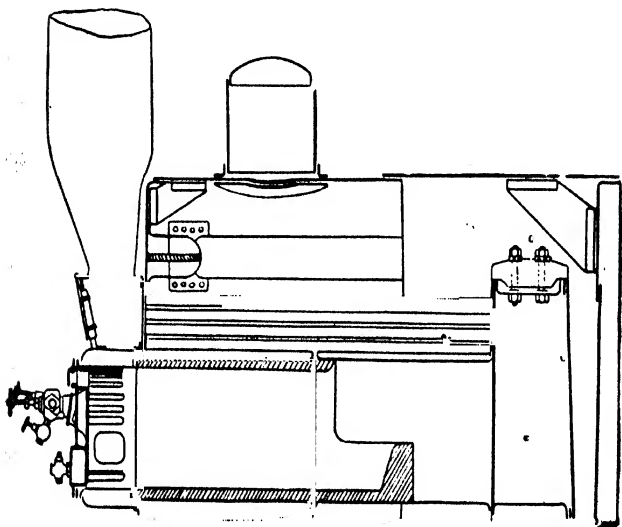


FIG. 29. LIQUID FUEL-FIRED FRENCH TORPEDO-BOAT BOILER.

agent. Though steam is very convenient its use involves so much loss of water and this is a disadvantage where water is scarce or hard or salt.

GRATES

The best grate is no grate at all. But the fire of solid fuel must be supported in order that air may be introduced to pass through it. Therefore the best possible grate is one which will admit

IMPROVED METHODS OF BURNING FUEL

air most freely and not allow too much of the fuel to drop unburned through the spaces. This statement suggests a mere mesh of wire, but such a support would speedily burn away. Experience has shown that for ordinary purposes, cast-iron bars from $\frac{1}{4}$ inch to 1 inch wide with air spaces of $\frac{1}{2}$ inch to $\frac{3}{4}$ inch act best. The proportions depend upon the size and nature of the fuel. A coal which must not be disturbed but must be left still on the grate to burn away can utilize a wider air space than is practicable with a fuel that needs frequent disturbance and is therefore liable to be shaken through into the ash pit. Dust fuel as described on another page is of such a nature that it can be burned without a grate for it burns before it has time to fall to the ashpit. Bar surfaces are often variously shaped and formed into numerous rectangular tables with a view to giving the best support and yet affording a maximum of air space (see below).

SPECIAL FIREBARS

An enormous variety of special firebars and grates are made as smoke prevention devices. Some of these bars are hollow and convey air to a split bridge heating the air in its passage. Other grates are so arranged as to divide the air which passes through them into a greater number of finer streams than do plain bars. A certain French firebar resembles a plain $\frac{3}{4}$ -inch bar cut across to form squares, the whole grate area being composed of

SMOKE PREVENTION AND FUEL ECONOMY

square surfaces $\frac{3}{4}'' \times \frac{3}{4}''$ or $\frac{7}{8}'' \times \frac{7}{8}''$, with air spaces of $\frac{1}{8}''$ to $\frac{3}{16}''$. Such a bar suits briquette fuel which has been made of washed coal and does not clinker, but it speedily chokes with clinker when used with even a Welsh coal like Powell-Duffryn, or Nixon's Navigation, and the clinker holds too firmly to be sliced cleanly up. Rocking bars have been much used to shake the fire. They serve to keep the fire open, will to some extent break up clinker, and will always get rid of dry ashes when not choked with clinker.

The rocking bar has been carried to an even greater extent in America, each transverse bar being capable of rocking so far back, that its surface assumes a vertical plane, and presents a series of fingers, which will cut out the bottom of a fire, and thoroughly clean it, without opening the door. Where clinker forms a plastic continuous layer, the front half of the grate can be rocked separately from the rear half. Clinker cools rapidly and becomes brittle, when the fire is taken from above it. To clean in such cases, the fire is all drawn to one end of the grate. The clinker rapidly chills, on the other half being opened by the bar movements. As soon as cold and brittle, the bars are rocked back to the cutting position, and the clinker cut into the ashpit. The fire is then pushed back upon the cleaned half of the grate, a little fresh fuel being added, if desirable, to furnish gas for the excess of air admitted through the bare grates, and the front half is similarly cut clean, and recovered with fuel. A more special

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American grate is the down draught variety, fuel being fired upon an upper grate of water tubes, and all gases escaping only downwards through the fire. A secondary grate below catches any fuel which falls freely through the somewhat wide upper spaces. With a thick body of upper fire the gases will come through fairly hot, and prepared to unite with the secondary air admitted between the two grates. In all these various appliances, success will be more or less obtained as the mixture of gas and air is able to unite and continue its combustion at a sufficient temperature. The steam jet admitted above the fire-door, and pointed towards the central part of the fire, is often employed to assist the inflow of air through the door grids, when the draught is otherwise insufficient. The steam jet appears sometimes to produce an effect out of proportion with its intensity, causing the flames to spring into great activity. Possibly this effect may be related to the supposed necessity for the presence of aqueous vapour when hydrocarbons are being burned, a point worth mention, if perhaps not fully established. Since the presence of aqueous vapour in the waste gases raises the specific heat considerably (see Appendix), it is more than doubtful, however, whether the increase of heat losses up the chimney, under such circumstances, does not more than balance the supposed gain.

Other moving bars are the chain grates, which are built up of flat links and pins and carried on a pair of polygonal end rollers. They receive fuel

SMOKE PREVENTION AND FUEL ECONOMY

their outer end and travel with it into the furnace. Such a chain grate was once used which travelled down the bridge outwardly, depositing ashes in a box in front of the boiler, all the coal being thrown against the bridge and therefore on the extreme back end of the grate surface. This gave excellent results, but failed because the draught winnowed out the dust from the fuel in its flight towards the bridge and choked the flues with dust, as also the rain gutters of all surrounding property. This of course is apt to be the case with all mechanical stokers which throw the fuel in a steady small dribble through the moving air above the fires, for the draught will always winnow out more or less of the finer dust.

DAMPERS AND DRAUGHT

A proper understanding of the action of a damper will do much to assist smoke prevention. Draught is regulated by means of dampers, which are simply sliding valves, or hinged doors, placed in the path of the gases. If a boiler is under-loaded, and has a large grate area, it is the common practice partially to close the dampers at the chimney base. This reduces the intensity of the draught, and diminishes the rate of combustion on the grate. Obviously the draught of air through the furnace door is also reduced, and sufficient air will not enter to burn the hydrocarbon gases above the fire. If this sluggish state is normal, the proper course to follow is to

IMPROVED METHODS OF BURNING FUEL

shorten the grate to such an extent, that the rate of coal combustion per square foot of grate surface per hour, shall be increased. With fair chimney draught, about 21 pounds may be secured, and the grate surface should be shortened until this rate is secured, more or less according to circumstances, providing always that a surplus possible damper opening still remains for emergencies. The shorter fire may often be kept thicker and a more efficient use of air can be secured. Mr. Longridge has obtained such results, and cut down the air supply below 15 pounds per pound of fuel.

If this draught question be considered in view of the necessity of admitting air through the doors, it will be perceived that much may depend upon the position of the dampers. If instead of dampers in the flue there is a damper placed to regulate the admission of air below the grate, there will be given the power of a double regulation. By adjusting the flue dampers the draught can be regulated to suit the flow of air through the door grids to the gases produced, whilst the ashpit damper will regulate the combustion of the solid carbon on the grate. The whole régime of the furnace can be kept under control by these two dampers, and it is as well to state here, that where there are two or more boilers, the flue regulating dampers should be those of each boiler, the damper at the foot of the chimney being usually fully open to pull in air over the fires.

Many careful firemen will slightly close the ashpit

SMOKE PREVENTION AND FUEL ECONOMY

dampers after firing, in order, if necessary, to add to the flow of air through the door grids.

On the general question of draught, and fire thickness, it may be laid down as a general law that large fuel, thick fires, and heavy draught, can be worked together. With too thin a fire, a heavy draught exerts a blow pipe effect in parts, and blows holes in the fire known as "volcanoes." It is not easy to force air through a thick fire of very small coal, as this lies too close to permit of free air passage. Hence the necessity in such cases of a thin fire and a gentle draught, and possibly a maximum combustion of as little as 12 pounds per hour per square foot of grate (nearly 60 kilos per square metre). Obviously the gentle draught necessary to avoid blow holes through the fire, reduces the flow of air through the doors, unless regulation is by the ashpit damper.

FORCED DRAUGHT.—In the event of insufficient draught, it becomes necessary to assist it. This may be accomplished in several ways.

The ashpit may be closed, and air forced into it by a fan, or by a steam worked injector. By these methods the indraught of air at the doors is of course shut off, or much reduced, and it is necessary that a passage for air should be made to conduct air from the ashpit to the inside of the door, whence it can escape through the inner perforated plate to the fire. The passage for this air must be controlled by a valve—automatically if desired—to admit air above the fire after stoking. (Further

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remarks on this subject will be found in Chapter IV.)

CLOSED STOKEHOLDS.—At sea the stokehold is closed, and supplied by fans with air at a considerable pressure, which is therefore as free to pass through the door grids as by way of the grate.

INDUCED DRAUGHT.—Usually for stationary work, a fan is placed at the base of the chimney to draw the waste gases from the boilers. This induced draught in every sense is managed like the natural chimney draught, the speed of the fan being capable of regulation down to the minimum intensity which will draw sufficient air above the fires. Assisted draught should always be capable of being so managed as to produce better combustion, enabling fires to be carried of greater thickness, producing more intense combustion, and higher furnace temperature, and generally improving the boiler efficiency if the fires are attended with corresponding care.

Fans are so arranged that their speed may be varied automatically by the steam pressure, the draught falling or rising as the steam pressure rises or falls. Dampers are also similarly connected with a diaphragm exposed to boiler pressure and arranged to vary the damper opening in accordance with the variations of steam pressure. The Erith Stoker Co. similarly vary the speed of their stoker to suit the varying demand for steam. But a variable fuel feed cannot be arranged instantaneously to reply to variation of steam pressure. This response of the fire is only possible when the draught also is automatically varied.

SMOKE PREVENTION AND FUEL ECONOMY

The importance of a minimum air supply, and a minimum chimney temperature, may be gauged from the facts that an ordinary furnace temperature is $2,500^{\circ}\text{F.}$ ($= 1,371^{\circ}\text{C.}$), and a chimney may have a temperature of 600°F. ($= 315^{\circ}\text{C.}$), thus showing that nearly a fourth of the heat has gone up the chimney. If by reducing the excess of air the furnace temperature is raised, and the chimney temperature is possibly reduced, there is not merely a less ratio of wasted heat thermometrically, but there is also a less weight of wasted gas at that temperature. To drive an induced draught fan may require 1 per cent. of the power generated in an ordinary good plant, or say, 10 h.p. for a 1,000 h.p. plant. But the chimney waste represents heat, which if equally utilized would give 333 h.p. under the above ratio of waste. If only 10 per cent. of this could be utilized by more extended feed heater surfaces, and less excess of air, it would represent 33.3 h.p. saved by the use of a 10 h.p. fan.

A steam induced draught can perhaps be worked with about 5 per cent. of the steam produced, and is not so economical as a fan.

The benefit of any forced draught comes in more especially where conditions are variable, as in an electric light station, where the worst draught is apt to accompany the maximum and most sudden demand for steam, as when a black fog descends suddenly on the district, and acts naturally as a damper on the chimney draught.

The disadvantages of induced draught as com-

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pared with *forced* draught are—that air leakage may easily occur between the boiler doors and the fan, and the volume of waste gases passing up the chimney may thus be unnecessarily augmented. If all the brickwork and dampers are tight, one system of artificial draught is as good as the other.

Some remarks on testing for draught will be found in Chapter IV, where the question of the air tightness of brickwork is also touched upon.

In all cases of forced draught the full benefit can only be secured when care is taken to maintain an even and sufficient depth of fuel upon the grate surface. Unless this be done much air will escape uselessly through the thin parts of the fire. It was very largely because of this that the Hopcraft furnace failed so miserably, for the air blown in under the grate escaped too freely through the annulus of fuel kept in constant looseness by the rotation of the circular grate within the circumscribing flat grate.

CHAPTER IV¹

The Examination of the Waste Gases, and Control of the Combustion Process

IT has been pointed out in Chapter II that four conditions are essential for the attainment of perfect and smokeless combustion, without loss of economy. These conditions are—

1. A sufficiency of air in the combustion chamber, but not an excess of the same.

2. A sufficiently high temperature in the combustion chamber.

3. A perfect admixture of the air and volatile hydrocarbons in the combustion chamber.

4. A sufficiently large combustion space. The absence of smoke is no absolute guarantee that perfect combustion and the highest economy are being obtained, for, as already observed, this absence of smoke may be the result of using a large excess of air in the combustion process. It is therefore necessary to have the waste gases passing to the chimney regularly examined, in order that the engineer in charge may know exactly to what extent the conditions of perfect combustion are being maintained in the furnace or boiler plant.

¹ Portions of this chapter are based on articles which have appeared in *The Times Engineering Supplement* of December 8, 1909 and in *The Electrical Review* of October 22, 1909.

EXAMINATION OF THE WASTE GASES

This examination must cover the following points—

- A. Colour and appearance.
- B. Draught and temperature.
- C. Chemical composition.

It is obvious that, in carrying out this examination, the methods and apparatus employed may vary from the most simple, to the most elaborate and expensive. In the following pages only the apparatus and methods adapted for works use will be described in detail. For the purpose of checking the combustion process as carried on upon a large scale, it is unnecessary that the methods of draught and temperature determination, or of gas testing employed, should be more than approximately correct, and if the margin of error is constant and is within 5 per cent., the results are of undoubted value for practical purposes. For description of methods and apparatus which yield more correct results, the reader is referred to the standard work on *Technical Gas Analysis*, by Winkler and Lunge (1902 edition).

A. COLOUR AND APPEARANCE OF THE WASTE GASES

When perfect combustion takes place, the gases while still in a flaming state are transparent. If the refractory combustion chamber of the boiler setting of Figs. 7, 12 or 14, be examined through a sight hole, it may be observed after a charge of fuel to be full of opaque gas or smoke, should there be an insufficient air supply above the fire. By opening the air grids and admitting air, the space

SMOKE PREVENTION AND FUEL ECONOMY

will be observed quickly to clear, and soon the opposite brickwork will become clearly visible and of a bright red or white-red colour. It is not possible to inspect a furnace properly without a coloured glass. The best glass to use is a violet blue. Flames looked at through such a glass will, if in a state of imperfect combustion, be resolved into streams of dark coloured gas. But when combustion is perfect, the interior of the furnace and the fuel assume a lavender grey colour, all rays of lower intensity being cut off by the glass. Red and yellow flames are cut out, and the ordinary flame from a grate directly under a water-tube boiler, from which the gases rise vertically between the cold tubes, will quickly be shown to possess very little radiant light capable of passing through blue glass. It appears probable that smokeless combustion cannot be secured unless the combustion is taking place at a temperature producing such light rays as will penetrate the blue glass. This penetrative power is an indication of the actinic power, and a proof of intense chemical action.

The process of combustion can very well be watched in this way; and the glass enables one to see the dun-coloured unburned gases as they travel in dark streaks towards the zone of perfect combustion, where they gradually disappear, becoming perfectly burned.

THE ESTIMATION OF SMOKE AND DUST.

Engineers will often find it necessary to estimate

EXAMINATION OF THE WASTE GASES

accurately the colour of smoke, so that its density may be stated. A standard chart ought to be decided on. There is nothing better than Ringel-

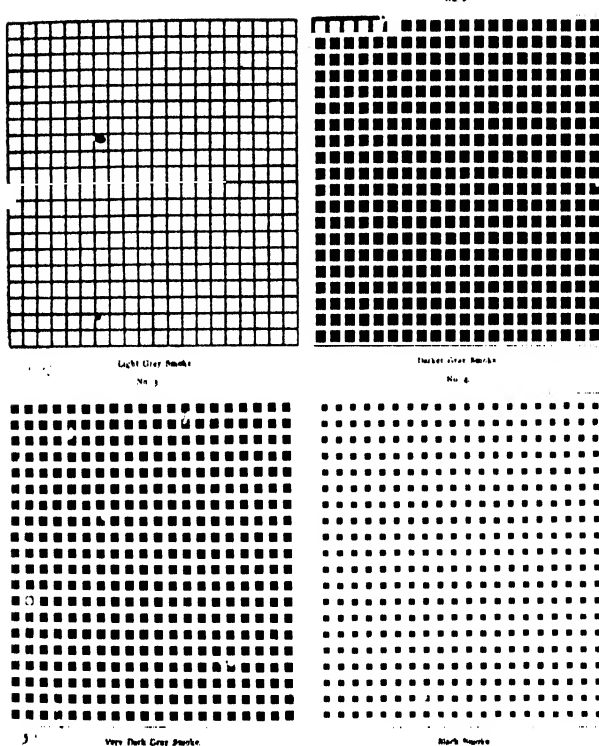


FIG. 30. RINGELMANN'S SMOKE CHARTS.

No. 0—All White. No. 5—All Black.

mann's smoke charts of six grades, viz. No. 0 to No. 5, named respectively nil, light grey, dark grey, very dark grey, black and dense black.

No. 0 card is pure white, and No. 5 is all black.

SMOKE PREVENTION AND FUEL ECONOMY

The other numbers consist of ruled black lines at right angles as follows—

No. 1.	Black lines 1 mm. thick, spaces 9 mm. wide.
" 2.	" " 2·3 " " " 7·7 " "
" 3.	" " 3·7 " " " 6·3 " "
" 4.	" " 5·5 " " " 4·5 " "

or in the same proportions.

The cards thus consist of a number of white squares divided by black lines. Placed 50 feet from the eye they take on the appearance of uniform colour, according to their naming. Such a card hung in the light in a line with the chimney top, enables the smoke density to be estimated very closely.

The cards ought to be at least eight inches square.

Fig. 30 shows four of these charts reduced in size.

An instrument called a smoke-tintometer has recently been designed by Mr. John Lowden, of Dundee, which overcomes some of the difficulties in the use of smoke charts, since it is handy in form, and is based on the same principle as Lovibond's tintometer. It consists of a metal tube having at one end an eye-piece, and at the other end two object apertures. In front of one of these apertures is fixed a revolving diaphragm, in which are five circular openings of the same diameter as the object aperture of the instrument. Four of these openings are filled with tinted glasses, corresponding to the standard tints of Ringelmann's smoke chart, while the fifth aperture remains clear. The observer when using this instrument turns the diaphragm to the clear portion, and holds the tube in such a

EXAMINATION OF THE WASTE GASES

position that one object aperture is in a line with the smoke emitted from the chimney under observation, and the other, or diaphragm aperture, is illuminated by clear sky. The diaphragm provided with the tinted glasses is then turned until both apertures appear to have equal, or approximately equal, illumination, and the number of the tinted glass required to yield this, is noted and recorded. Since the tinted glasses are graduated from the standard tints of Ringelmann's charts—namely, No. 1 light grey, No. 2 dark grey, No. 3 very dark grey, and No. 4 black smoke—the observer is relieved from the difficulties met with, in the use of the charts for practical purposes, and still obtains a record of equal scientific value. Given a reliable and unbiased observer, the records obtained with this instrument should be sufficient to obtain convictions in a court of law—although no doubt the photographic method described by Swinburne in *The Times* of March 20, 1907, since it provides a permanent record and eliminates the personal equation, is the better one of the two. Even photographic records, however, may be faked by an unscrupulous inspector, and therefore for practical purposes the smoke-tintometer may be said to meet the need of the moment satisfactorily.

Turning now to the observation and recording of smoke for factory management purposes, there are several methods which may be adopted with advantage. The simplest means of enabling the fireman to know what amount of smoke he is producing

SMOKE PREVENTION AND FUEL ECONOMY

is to arrange for the chimney top to be visible from the firing-plate of the boilers, by the provision of silvered glass reflectors at the required points on the intermediate buildings. This plan was proposed first by one of the Authors in a paper read in 1903, and it has now been adopted in many works and factories. When this plan is impracticable, that proposed by Messrs. Bonham and Weber of Chicago may be adopted. In the main flue or breeching at the base of the chimney a perforated ring pipe is introduced, and from this point a sample of the exit gases is continuously abstracted by means of a small fan and is forced through a system of pipes to a miniature *Smoke-stack*, placed in a prominent place on the firing-floor of the boilers.

The draft conveying the sample of exit gases to this miniature smoke-stack is carefully regulated so that the proportion between the size of the latter and volume of gas discharged is the same as that obtained in the larger chimney. If desired, the pipe from the breeching can also be continued to the office of the works engineer or manager, and the sample of exit gases be discharged outside, after passing through a glass bulb or flask, fixed by cement upon the metal piping. In this way, both the fireman and engineer have constantly under their eyes an indication of the density of the smoke emitted from the chimney of the works. Allowance will have to be made, however, for the difference in diameter of the miniature and real chimneys. A column of smoke which appears light brown, when seen

EXAMINATION OF THE WASTE GASES

through a depth of only six inches, will be many degrees darker and may even appear quite black when viewed through a depth of 12 feet or more. This, it may be pointed out here, was the defence which rendered abortive the prosecution of the Underground Electric Railway Co. for excessive smoke emission from the chimneys of the Lots Road, Chelsea, Generating Station in July 1907, the chimneys of this station having the unusually large diameter of 19 feet. Messrs. Bonham and Weber have further developed this method of smoke observation, by allowing portion of the exit gases drawn from the base of the chimney, to impinge upon a piece of white tape, chemically prepared to retain the soot and dust, this tape being moved continuously by clockwork past the slit through which the gases are forced. A permanent and continuous record is thus obtained of the density of the smoke emitted from the chimney top. Professor Goodman has modified this arrangement, by dispensing with the chemical treatment of the tape, and in his smoke recording apparatus the gases are simply forced *through the tape* as it is drawn by clockwork over an orifice in the pipe from which the gases issue. The engineer-in-charge of boiler plant, therefore, should have no difficulty now in obtaining a close observation of his chimney top, and if he also desires it, a permanent record of the smoke density, by means of one or other of these comparatively simple methods. In every case, however, care will have to be given to the regular and systematic cleaning of the connect-

SMOKE PREVENTION AND FUEL ECONOMY

ing pipes and of the collecting ring, if accurate observations are to be maintained for any length of time ; since otherwise with a badly-fired boiler plant, these will soon be stopped up with dust and soot, and beautifully clean records, due to air-leakage, will be obtained.

Finally the methods and apparatus for observing and recording the amount of dust and soot in the atmosphere of cities and large towns may be described briefly.

These are similar in principle to the Bonham and Weber method, and depend upon the continuous abstraction of a sample of the air at selected points, and the forcing of this after measurement through some material which retains the soot and carbon in a form in which it can be estimated or weighed, at the end of stated intervals of time.

The apparatus devised by Hahn consists of a double cylinder pump worked by an electric-motor, driven by accumulators, the volume of air in this case being measured by the counter attached to the pump. The air is forced through a tube containing collodion wool, and the final estimation of the soot and dust is made by dissolving this wool in a mixture of two parts of ether and one part of alcohol, and by comparing the turbid fluid containing the soot and dust in suspension with various standard solutions containing known amounts of soot and dust.

Rübner has modified this method, by substituting a filter paper for the collodion wool. Further details of the apparatus used in these two methods of smoke

EXAMINATION OF THE WASTE GASES

and dust estimation will be found in an article which appeared in the 1911 January issue of *Cassier's Magazine*.

B. DRAUGHT AND TEMPERATURE

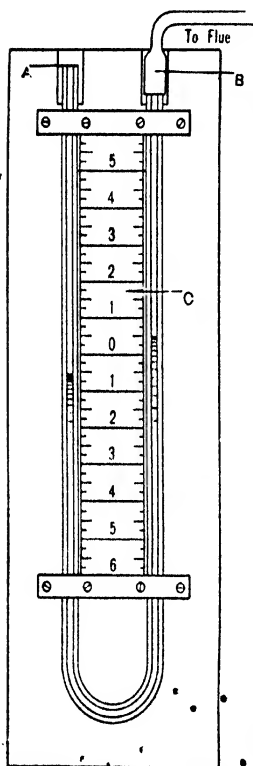
These measurements should be carried out at an observation-hole, placed in the top or side wall of the branch-exit flue of each boiler or furnace, at that point where it joins the main-flue to the chimney. There is usually a damper at this point, and the observation-hole should be about 24 inches, on the furnace or boiler side of it.

It saves much trouble if such holes are left in the brickwork when the flues are being constructed, and a 30-inch length of 1 $\frac{3}{4}$ -inch wrought-iron pipe with a flanged top should be set with fire-clay in the hole thus left, in order that a straight and clear passage into the flue may be kept constantly ready for use. When not required for testing purposes, this pipe can be closed with a 1 $\frac{1}{2}$ -inch bolt.

For comparative rough draught measurements the apparatus shown in Fig. 31 is sufficiently exact. The U-tube is 6 $\frac{1}{2}$ inches in height, and of glass $\frac{1}{16}$ inch inside diameter. It is half filled with water, or in special cases with some lighter and more mobile fluid. The limb marked B is connected to a hard glass tube, passing at least two feet into the flue, and firmly fixed in the observation-hole by cotton waste. The scale C behind the U-tube slides in a groove, and this movement enables the water

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level to be easily adjusted to zero, before making the test, and thus saves trouble when filling the tube. Should the pull of the chimney be equal to less than one inch of water, a greater range of reading can be



obtained by connecting the limb A to the flue by a second hard glass tube, with its further end bent at right angles, and turned in the direction from which the gases are travelling. This tube must project well into the flue for accurate results. The readings of the apparatus can also be amplified by using ether or alcohol, in place of water, for filling the U-tube, but in this case a calculation will be requisite in order to obtain the draught measurement expressed in inches of water, the factor depending upon the specific gravity of the liquid used.

FIG. 31. DRAUGHT MEASUREMENTS GAUGE.

This instrument, in more elaborate form, can be employed for measuring the speed of the draught in boiler and furnace flues, and is then known as the "Anemometer."

For a full description of its use for such purposes,

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and the methods of calculation, readers are referred to the larger books on this subject, by Lunge and Poole.

As regards the draught which ought to be maintained in each boiler-flue in order to obtain perfect combustion of the fuel, a pull equal to at least $\frac{3}{4}$ -inch of water ought to be observed at the point named, when the furnace doors and air slides are closed and the dampers are drawn to their full extent. This would signify a 1-inch pull at the base of the chimney. If this difference in water level is not found when making the test with the draught-gauge, a special examination should be made of the condition of all the brickwork of the flues and boiler casings, and where necessary pointing should be undertaken. If no improvement results, steps must be taken to reduce the work placed on the one main flue or upon the one chimney—for perfect combustion is impossible in the absence of sufficient draught, and many failures to attain it are no doubt due to this simple cause.¹ The engineer in charge of the boiler or furnace plant ought therefore to make daily tests with the gauge just described on every furnace and boiler under his charge, and any deficiency in draught should at once be noted and remedied. Too low a temperature of the exit gases is in some cases the cause of defective draught. The draught above the boiler fires should be about $\frac{3}{4}$ -inch, when working under normal conditions.

¹ Defective baffle walls, at the base of the chimney, are sometimes the cause of defective draught.

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The temperature measurements can be made with ordinary mercury thermometers up to $300^{\circ}\text{C}.$; or with mercury thermometers of a special type up to $530^{\circ}\text{C}.$ For temperatures above $530^{\circ}\text{C}.$, either a water pyrometer, or an electrical pyrometer of the Chatelier type, must be employed.

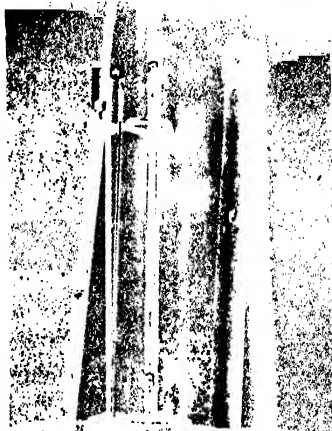


FIG. 32. CARRIER FOR MERCURY THERMOMETER USED IN TESTING FUELGAS TEMPERATURES.

A case and carrier suitable for a mercury thermometer, designed for taking the temperatures of furnace and boiler flues, is shown in Fig. 32. *A* is a "high temperature" mercury thermometer constructed of special hard Jena glass, containing nitrogen under pressure in the upper portion of the stem, and graduated up to $550^{\circ}\text{C}.$ *B* is a strong

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case of 1-inch brass tubing into which this thermometer fits ; the lower portion *C* being filled with brass filings, which serve as a protection and heat carrier to the bulb of the thermometer. This lower portion of the case *C* screws into the main tube, and the thermometer is fixed into the casing by aid of asbestos plugs and two brass washers. When required for use, the brass casing *B* is fixed in the iron carrier *D*, which is constructed of $\frac{1}{2}$ -inch wrought-iron rod, and is flattened out at the lower end to permit of the brass thermometer being fixed firmly upon it. A hollow step holds the base of the brass case, and a sliding cover *E* is used to hold the top of the case firmly against the iron rod. The carrier *D* can be made of any length, and is provided with a handle at its upper end, so that it may be hung in the observation-holes in any of the flues for obtaining temperatures. Owing to the mass of filings which surround the bulb of the thermometer, and to the thickness of the brass casing, the thermometer must be left at least ten minutes in the flue before withdrawing for reading the temperature ; and some little practice will be requisite to obtain quick readings of the mercury level on withdrawal. It is necessary to have the light at a particular angle for this purpose ; and to have cotton waste handy, for removing soot from the glass. An oil lamp or candle will be found most convenient for obtaining the readings quickly. The mass of metal surrounding the thermometer is here of some advantage, since it causes the loss of heat to

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be slow. *F* is a stout wooden case for protection of the thermometer when not in use.

The "high temperature" mercury thermometers are expensive and fragile, and for works use the water pyrometer is a more practical and useful instrument. Fig. 33 is from a photograph of an inexpensive water pyrometer which can stand much rough usage, and yields results sufficiently accurate for ordinary works requirements. *A* is a small piece of wrought iron, $1\frac{1}{8}$ inches in length and $\frac{5}{8}$ inch in diameter; *B* is a tin measuring vessel holding 118 cc. of water when filled to the brim; *C* is a cup of hard lead, about $2\frac{3}{4}$ inches in diameter and 3 inches high, holding about 236 cc.; and *D* is a carrier for the small iron block *A*. This carrier is similar in design to that shown in Fig. 32, and is provided with a sliding hood which holds the iron block in position, and also protects it from soot; this last being a very important detail.

The water pyrometer is used, by inserting the block of iron in the carrier *D*, and by placing the latter in the observation-hole of the flue, the temperature of which is required. The block and carrier must remain at least ten minutes in this position. While the carrier and block are attaining the temperature of the flue, 118 cc. of clean water are measured off into the lead cup *C*, and the temperature of this water is carefully taken with a thermometer reading up to 50°C . and graduated in fifths of a degree. The cup *C* and its contents must be placed on a support, which is at the temperature of the

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air, as it would obviously lead to error if the cup were placed on warm brick-work, or upon a hot boiler-plate, during the observation. This warning may seem superfluous, but users of this instrument, in some cases, will, no doubt require to be told to take this obvious precaution.



FIG. 33. WATER PYROMETER FOR TESTING THE TEMPERATURE OF FLUE-GASES.

After the water in the cup *C* has arrived at a permanent temperature, and the necessary ten minutes have elapsed, the holder *D* is withdrawn from the flue, and the portion containing the iron block is held horizontally just above the cup, from which the thermometer has been removed. A short piece of stout iron wire is used to push back the cover along the carrier, and the block of heated iron is

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allowed to fall into the water. The cup is then gently rocked to agitate the water and the block, and also to prevent softening or fusion of that part of the lead bottom upon which the iron block rests. After the lapse of one minute, the thermometer is again inserted and the readings taken. The rocking motion is again employed for another half minute, and a second thermometer reading is taken. If no rise of temperature be noted, the observation is complete; if a slight rise of temperature occurs, the agitation of the block and water is renewed for another quarter minute.

The calculation which is necessary to obtain the flue temperature depends upon the relative weights of the block, of the lead cup, and of the water; and for works use, it is advantageous to arrange that a simple factor, say 25 or 50, shall yield the required result.

The formula for calculating the temperature is as follows—

$$T = t^1 + \frac{p^1 (t^1 - t)}{pc}$$

where T = the temperature of the flue or block.

t = temperature of the water in the lead cup before the observation.

t^1 = temperature of the water in the lead cup after the observation.

p = the weight of the iron block.

c = specific heat of the iron.

p^1 = the weight of the water within the lead cup, plus the water equivalent of the cup. The last is obtained by multiplying the weight of the cup, by the specific heat of the hard lead, namely —0.35.

The portion of the above expression $\frac{p^1}{pc}$ may, as

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already stated, be converted into a constant factor (x) and the formula then becomes—

$$T = t + x (t' - t)$$

—that is, the temperature of the flue is equal to (x) times the gain in temperature of the water in the cup, added on to the final temperature of the water. For determining high temperatures, the factor should not be less than 50, otherwise the water in the cup will be raised beyond the reading limit of the thermometer; for low temperatures a factor of 25 will yield satisfactory results.

• In the water pyrometer shown in Fig. 33, the iron block weighs 46.1 grms., and the water equivalent of the cup is 18.00 grms. When using 118 cc. of water in the cup, the factor (x) is 25.9, and when employing 200 cc. of water, the factor is increased to 41.5.

The errors of this instrument are due to radiation losses, which are partly guarded against in the more elaborate forms of it devised by Fischer and by Siemens and Halske, and to changes in the specific heats of iron and of lead, as the temperature increases. Corrections can be made for this latter error, when greater accuracy is desirable, but for merely comparative works tests, these corrections are unnecessary.

Pyrometers of the electrical type are based, either upon the changes in electrical conductivity due to the rise in temperature, when the active portion of these instruments is inserted in the hot flue, or upon the current set up in thermo-couples, under similar

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conditions. The more expensive forms of these instruments yield accurate results, and when provided with recording cylinders, they form the most convenient means for checking flue temperatures. They require calibrating at stated intervals, however, as they alter during use. For descriptions of these instruments and of their applications, readers may consult the larger works on this subject by Lunge and Poole. A recording pyrometer based on the pneumatic principle is also largely used in America, and is known as Uehling's pneumatic pyrometer. A brief description of it is given in Poole's book on *Fuel*, 1901 edition, p. 153. This instrument is stated to yield reliable results for all temperatures.

The Féry radiation pyrometer is one of the best instruments for taking furnace temperatures. The principle of construction is such, that it can be placed any convenient distance from the source of heat to be measured, and a correct reading can be obtained by a simple adjustment.

As regards the temperature which ought to be maintained in boiler furnaces in order to obtain perfect combustion, the following figures are given for a Lancashire boiler by Hiller¹—

Temperature in boiler furnace	1,535°C.	2,800°F.
Temperature six feet behind bridge	980°C.	1,800°F.
Temperature in drop flue at end of tube	535°C.	1,000°F.
Temperature at exit into main flue	340°C.	650°F.
Temperature at base of chimney (maximum)	150°C.	300°F.

¹ *The Working of Steam Boilers*, by E. G. Hiller, 1907.

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When economizers are used for heating the feed-water of the boiler, the temperature is usually reduced by about 250°F. , and the waste gases pass to the chimney at a temperature of 400° to 450°F. An exit temperature from the boiler flue, before entering the economizer, above 340°C. or 650°F. , is indicative of bad work, and is a sign of dirty flues, or of scale-covered boiler plates. When such a temperature is recorded for any boiler, its cause should be at once discovered, and, if possible, there should be no delay in remedying it.

An economizer minimizes, but does not obviate, the losses resulting from too high a temperature of the exit gases; and the boiler is the appliance in which all the heat possible should be abstracted from the hot gases. To allow unnecessary heat units to escape into the flues, with the idea that they will be caught and retained by the water passing through the economizer, is not conducive to true economy.

C. CHEMICAL COMPOSITION OF THE WASTE GASES

a. SAMPLING THE GASES

The composition of the waste gases passing from each boiler may be ascertained by examining a sample taken from the observation-holes situated just inside the damper of each branch exit flue, and already described under draught and temperature. If an *average* sample of the waste gases passing from a group of boilers is required, this must of

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course be taken at a point in the main flue, where the gases passing from the individual boilers have travelled some distance together, and have become well mixed. If the sample of exit gases be drawn from the chimney stack, the sampling hole must be placed at least thirty feet from the ground, since the baffle walls built at the base of the chimney hinder admixture of the gases passing up it, until they have travelled some distance from their entrance point. The sampling holes for drawing samples of the waste gases should be constructed as already described, under Section B; and as it is convenient to be able to make temperature observations at all these points, the wrought-iron pipe used should be $1\frac{3}{4}$ inches in diameter in all cases, in order to admit the thermometer carrier. Gas samples taken at man-hole covers are wholly untrustworthy, since air always leaks in when sampling is attempted at these places.

For drawing the gases from the flues, three-foot lengths of the glass tubing, sold as "hard glass," $\frac{3}{8}$ -inch in external diameter, are the most convenient. A large bung $1\frac{3}{4}$ inches in diameter is fixed upon one of these tubes, and is inserted in the flanged end of the wrought-iron pipe. A second length of glass tube is then connected to the projecting end of the first, by a three-inch length of good red rubber tubing, as black rubber is not suited for use with hot gases. It is not advisable to use any apparatus for retaining the soot at this stage of the sampling operation, since the volume of the gas drawn through

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the tubes may be very large, and asbestos or glass wool speedily become blocked with the soot which collects in it. .

The form of sampling apparatus employed depends upon the character of the test, and varies according as one desires a test representing the composition of the gases at a given moment, or an average extending over one or twelve hours. Three forms of sampling apparatus, designed for fulfilling these different conditions, are described below.

I. SNAP-SAMPLES

Fig. 34 shows the most convenient form of apparatus for taking what are called "snap-samples," that is, samples of the waste gases at any given moment of time. *C* is a small rubber finger pump, provided with valves, so that the gases forced through it travel only in the one direction. A pump that passes 35 cc. at each compression is the most convenient size for general use. *B* is a small check valve, and is formed by a short length of black rubber tube $\frac{1}{8}$ inch in diameter, having a central slit longitudinally, and closed at one end with a sealed length of glass tube pierced with a small hole where it comes under the slit in the rubber. This tube acts as a support to the rubber tube, and to prevent collapse. The valve is enclosed in the glass tube *B*, and serves to prevent all possibility of air leaking past the valves of the pump *C*, into

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the gas-sample tubes, *A* and *D*. *A* is a Honigman gas burette, holding 100 cc., and graduated in one-tenths, the use of which for CO₂ determinations will be explained in the next section. *D* is a larger gas-sample tube holding 220 cc., and provided with glass stop-cocks at each end. It serves to retain samples of the gas for some hours without change, and is useful for storing reserve samples, or samples to be sent to the expert for complete analysis. These

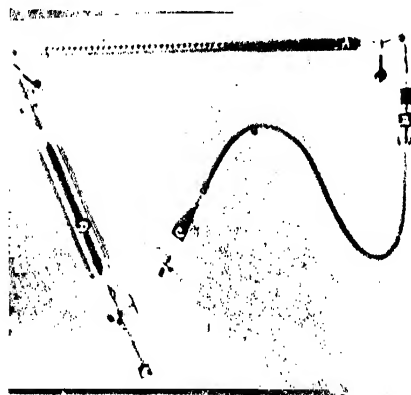


FIG. 34. APPARATUS FOR OBTAINING SNAP-SAMPLES OF FLUE-GASES.

various portions of the apparatus are connected together by rubber tubing, and *D* is connected to the hard-glass tube leading into the flue by the rubber connexion *E*. The sample is taken by pumping the waste gases through the sampling tubes *A* and *D*, until all the air has been expelled, and its place is occupied by the flue gas. Five times the volume of air contained in either tube must be passed through

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them in order to attain this result ; and a simple calculation shows that with a rubber pump, expelling 35cc. at each compression, 46 compressions, or suction^s will be required to replace the whole of the air in tubes *A* and *D* with waste gases.¹ This number of compressions can be easily effected in one and a half minutes. Ordinary chemical spring clips are then fixed upon the rubber tubes at each end of the Honigman burette, the stop-cocks on *D* are closed, and the various portions of the sampling apparatus are disconnected. The testing of the gas in the Honigman burette must at once be proceeded with since rubber connexions are not permanently gas-tight.

The precautions necessary in using this apparatus are—

First. To see that the valve *B* is working properly, and that the two lips of the slit meet and close evenly, when the pump is being compressed in the hand.

Second. To have the interior of *A* and *D* fairly dry before use ; and

Third. To see that all the rubber connecting pieces are tight and free from kinks, when the sampling operation is in progress.

This “dry” method of sampling is certainly the most convenient of those which can be applied to the sampling of flue gases ; and even in unskilful

¹ Allowance should also be made for the air contained in the sampling tubes leading into the flues, which may represent another 250 cc.

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hands, it yields accurate results. Unfortunately, it cannot be applied to the withdrawal of samples from the flues over any long period of time.

2. AVERAGE SAMPLES EXTENDING OVER ONE HOUR

The apparatus shown in Fig. 35 is employed when a sample of the waste gases during a period not exceeding one hour is required. *A* is an ordinary water-jet air pump, sold by chemical apparatus dealers to chemists, for laboratory purposes. *B* is a 220 cc. glass sample tube provided with glass stop-cocks; and *C* is the rubber connexion which serves to join the T-shaped connecting piece to the glass tube leading to the flue. *D* is a rubber connexion ending in a glass jet. The water-jet pump must be connected to a water supply. Should there be none convenient to the place where the average sample is to be taken, the pump must be connected by a syphon tube to a bucket or tank of water placed ten feet above the ground, and a screw clip must be used to regulate the flow of water into the pump. The tube *B* must be filled with mercury, and must be fixed in a suitable support in a vertical position with the jet on *D*, leading into the bottle in which the mercury is stored when not in use. This jet must dip under the mercury level in the bottle when the sampling tube is empty. Water is unsuitable for use in *B*, since absorption of CO_2 occurs, when the liquid and gas are left in contact for one hour.

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The average sample of gas is now obtained in *B* by starting the water-jet pump at such a rate of flow, that a fairly rapid current of waste gas from the flue is carried through the tube *C* and through the T-piece connexion into the pump. The upper glass stop-cock on *B* is now opened to its full

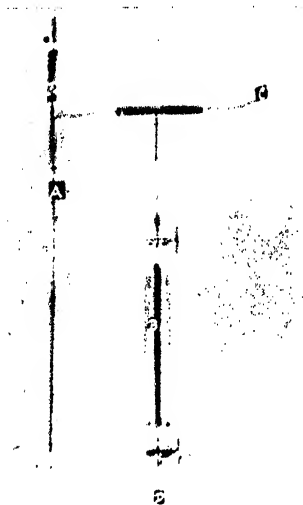


FIG. 35. SAMPLING APPARATUS FOR OBTAINING AVERAGE SAMPLES OF FLUE-GASES DURING ONE HOUR.

extent, and the lower one is opened sufficiently to allow a slow stream of mercury to pass out of *B* into the storage bottle. The jet on *D* enables the stream of mercury to be regulated with ease; and the rate of flow is arranged so that the vessel *B* shall be empty in one hour, or in the time to be covered by the sampling operation. During the whole of this

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period, a rapid flow of waste-gas is being drawn through the T-piece to the pump; and the gas which enters *B* is therefore a fair average sample of the whole bulk. The precautions necessary in using this apparatus are—

First. To see that the water-pump *A* is working properly, and that there is no danger of back suction of water into *B*, and into the tubes leading into the flue. When the pressure or head of water is too small, this is a possible cause of danger to the sampling operation.

A dirty water supply may also cause trouble, for it will probably lead to stoppage of the pump; owing to lodgment of particles of solid matter in the jet. A small plug of glass wool placed in the suction end of the syphon tube, will obviate this danger.

Second. To see that the mercury bottle is so arranged under *B* that when this tube is filled with gas, the point of the jet shall be dipping in the mercury and shall not be exposed. Otherwise air would diffuse into the sampling tube, if some one were not present to close the stop-cock on *B*, at the exact moment when it became empty. The delivery tubes of the pump *A* should also dip into a vessel of water, for the same reason.

Third. To see that all the rubber connexions are tight and free from kinks, during the sampling operation.

This sampling apparatus, if fixed in a suitable stand, is the most convenient for taking hourly averages of flue gases. By employing two sampling

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tubes, a second sample of gas may be taken while the chemist or engineer is examining the first ; since, when once started under correct conditions, the apparatus requires no attention until the end of the hour.

3. AVERAGE SAMPLES EXTENDING OVER SIX OR MORE HOURS

Fig. 36 shows, in diagrammatic form, an average gas-sampling apparatus that has been thoroughly

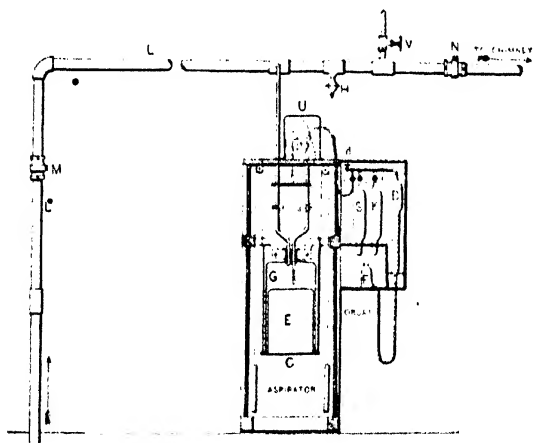


FIG. 36. SAMPLING APPARATUS FOR TAKING SAMPLES OF FLUE-GASES, OVER A PERIOD OF SIX OR MORE HOURS.

tested by the engineers of the Hamburg Smoke Abatement Society and is now installed in a very large number of steam-boiler plants in that city.

The sample of gas is drawn constantly, using natural or artificial draught, from the exit flue by means of the pipe *L*, and as it passes over the aspirator *C*

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a small portion of the gas flow is sucked down into this by the action of clockwork on the bell *E*. The aspirator above this bell is filled with water, covered with a film of paraffin oil, and the rate at which the bell sinks and the gas is sucked into the space *G* above it, is controlled by a pendulum and simple clockwork arrangement at *U*, the speed of which can be varied to suit the length of firing shift. At the end of eight or twelve hours, i.e. when the firemen change, the clockwork is stopped, and the average sample of gas stored in the space *G* is tested for carbon dioxide and for oxygen, by aid of the Orsat apparatus shown on the right-hand side of the aspirator, a rubber tube being employed to connect the aspirator and Orsat apparatus.

Two tests of the average sample of gas are made, and the aspirator is then emptied by raising the bell *E*, and by opening the taps *A*, *C*, and *d*.

By closing *A* and opening *B*, and by starting the pendulum of the clockwork again, the apparatus is set for taking the next average sample, no attention being required for eight or twelve hours, according to the length of the working shift.

TESTING THE GAS SAMPLE

The sample of the waste gases obtained in one of the three ways just described, may be tested for carbon dioxide (CO_2) alone,—for CO_2 and oxygen (O), or, for " CO_2 ," O , and carbon-monoxide gas (CO). The necessity for making tests for carbon monoxide

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gas is the greater, when high percentages (30 per cent. and above) of carbon dioxide gas are being obtained, for the reasons which are explained briefly on p. 151. Three forms of gas testing apparatus will now be described.

I. SIMPLE APPARATUS FOR CO_2 TESTS ALONE

A Honigman gas-burette is the simplest apparatus for making tests for CO_2 alone; the method of enclosing a sample of the gas to be tested in this burette, has already been described on p. 118. Fig. 37 shows the burette in use. The burette consists of a measuring tube holding exactly 100 cubic centimetres, and divided for 20 cc. of its length, at its lower end, into fifths. Both ends are tapered for connecting to the other portions of the sampling apparatus by lengths of rubber tube, and the upper end of the burette is closed by a single-way glass tap (*a*). The lower end is provided with a piece of good rubber tubing, which is closed when required, by a strong clip. After the sample of gas has been taken as described on p. 118, the burette is allowed to stand in a cool place for 15 minutes, in order to bring the temperature of the contained gas down to 15°C . The end of the rubber tube projecting beyond the closed clip is now bent upwards and is carefully filled with water to expel the air. The burette is then immersed, as far as the zero mark, in the solution of caustic potash contained in the cylindrical jar

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C, 16 grams KOH being dissolved in 100 cc. of water to form this solution.

The tap *a* is then opened for a moment, in order to equalize the pressure within and without the burette, and after closing it again, the burette

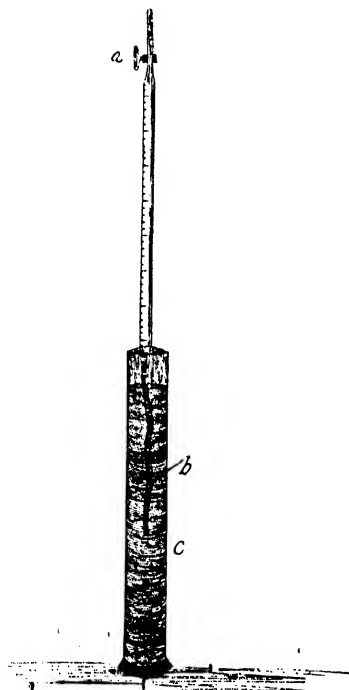


FIG. 37. HONIGMAN GAS-BURETTE IN USE.

which now contains exactly 100 cc. of the gas, is immersed deeply in the KOH solution. The internal walls of the burette are in this way wetted with the KOH solution, and absorption of the CO_2

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at once commences. This can be accelerated by withdrawing the burette from the jar and by bending it downwards, still keeping the lower and open end of the rubber tubing well below the surface of the potash solution.

In a few minutes, the time varying with the freshness of the KOH solution, the absorption of CO_2 is complete. The burette is again immersed in the liquid contained in the jar, until the levels within and without the tube are the same, and the reading is then taken. The volume of gas that has disappeared by absorption, gives the percentage of CO_2 contained in the gas-sample, without any further calculation. With care, this apparatus gives fairly accurate results (within 50 per cent. of the actual percentage); the leakage of air into the connecting tube when removing the clip, and the cooling of the gas sample, being the two points that require attention in its use. The KOH solution also requires renewal frequently, unless kept in a closed bottle between the tests, and the gas burette itself must be well rinsed and dried, before using again.

The apparatus required costs only 8s., and a test can be made in five minutes when the KOH solution is ready for use.

2. TESTS FOR CARBON DIOXIDE AND OXYGEN.

The Fischer gas-testing apparatus is the most convenient form for use where only two components of the waste gases are to be estimated, and Fig. 38

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shows the simplest form of the Fischer apparatus.

The essential parts consist of a water-jacketed gas burette, holding 100 cc., and graduated in fifths on the narrow part of the tube; and two absorption

pipettes filled with narrow glass tubes, connected to the measuring burette by an overhead T-piece provided with cocks. The absorption pipettes are kept filled with the necessary absorbing reagents. A solution of caustic potash is used for absorbing the carbon dioxide, and one of pyrogallic acid in caustic potash, is employed for absorbing the oxygen. The details of the manipulation of this apparatus are exactly similar to those governing the use of the Orsat-Lunge gas-testing apparatus, and readers are referred to the next section

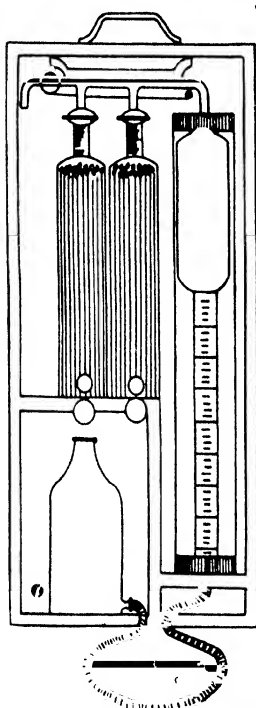


FIG. 38. FISCHER GAS-TESTING APPARATUS.

for instruction in its use. The Fischer apparatus is small and compact, and is contained in a case which has a sliding front and back; and measures only 18"×9"×5". The necessity for

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cleaning out the absorption pipettes at intervals, and the presence of liquids, does not render the apparatus so convenient for transport, or so suitable for rough work's use, as the Honigman gas burette, in the modified form described in the last section.

3. TESTS FOR CARBON DIOXIDE, OXYGEN, AND CARBON MONOXIDE

The best form of apparatus for use, when these three constituents of the waste gases are to be estimated, is the well-known Orsat-Lunge gas-testing apparatus. Fig. 39 shows this in its simplest form. Its essential parts are a water-jacketed gas burette *M* holding 100 cc. ; and graduated for the first 30 cc. of its volume ; three absorption pipettes, *E*, *F* and *G*, connected to the measuring burette by a horizontal T-piece *i*, *i*, and glass stop-cocks, *c*, *f*, *g* ; and a rubber finger-pump *K* and water-bottle *I*, for bringing about the transfer of the gas sample from one vessel to another.

The absorbing solutions used are caustic potash, pyrogallic acid in caustic potash, and ammoniacal cuprous chloride, in the order named, for the CO_2 , O , and CO respectively.

The solutions should be of the following strength—

Caustic Potash.—A solution of Sp. Gr. 1.20. The absorption pipette requires about 150 cc. to fill it to the requisite level for use, and this amount of solution is obtained of the desired strength by dis-

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solving 23 grams of caustic potash in 140 cc. water.

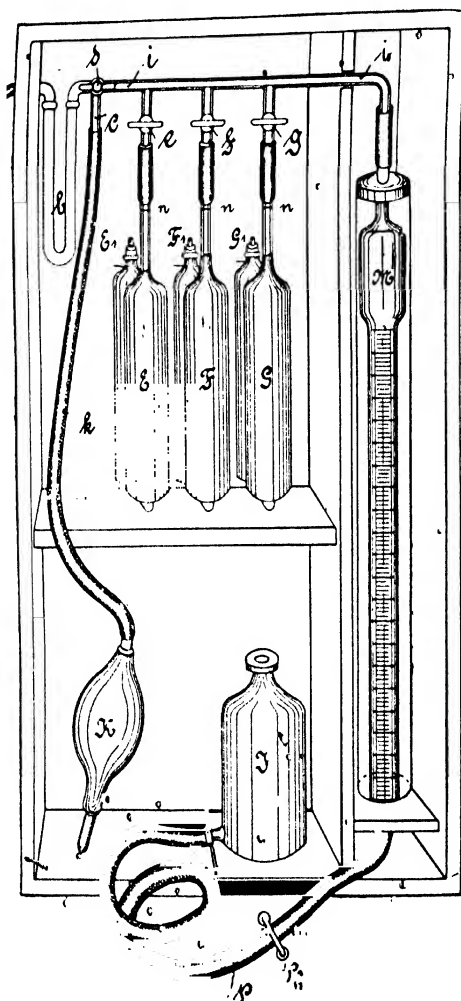


FIG. 39. THE ORSAT-LUNGE GAS-TESTING APPARATUS.

One stick of caustic potash of the usual thickness

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weighs about 14 grams; and it is most convenient to determine the weight of one stick, and then to obtain the required weight in future by dissolving $1\frac{1}{2}$ or $1\frac{2}{3}$ sticks in 140 cc. water. It is not advisable to make a large quantity of the solution and to store it, since a solution of this strength is apt to cause glass stoppers to stick fast in the necks of bottles, and if kept in a corked bottle CO_2 absorption occurs.

Pyrogallic Acid.—A solution of 20 grams of pyrogallic acid, in caustic potash solution of 1.20 Sp. Gr. The caustic potash solution (150 cc.) is first prepared as above, and after cooling, it is poured on to the weighed amount of pyrogallic acid, contained in a small flask. This must be kept corked while solution occurs, and the whole must then be transferred without any unnecessary exposure to the air, to the second absorption pipette. The solution of pyrogallic acid in caustic potash is of a dark brown colour, and it deepens rapidly in tint, owing to oxygen absorption and to the formation of coloured organic products.

Ammoniacal Cuprous Chloride.—250 grams of ammonium chloride are dissolved in 750 cc. of water, and 200 grams of cuprous chloride (Cu_2Cl_2) are added. The whole is agitated in a closed flask or bottle, until only a slight amount of insoluble oxychloride remains. The solution is a brown liquid, which does not change much if kept out of contact with the air. When required for use, 35 cc. of ammonium hydrate (Sp. Gr. .91) are mixed with

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105 cc. of this solution, and the whole is transferred at once to the absorption burette. As this solution absorbs carbon dioxide and oxygen, as well as carbon monoxide, it loses strength rapidly on exposure to air; and even when confined in the absorption burette, it changes much too quickly in composition. If the gas-testing apparatus is only in occasional use, it is therefore wise to empty the third absorption pipette after each test.

Filling the Pipettes.—The Pipettes after thoroughly washing and filling with the glass tubes, are fixed in position on the stand, and a funnel is attached by a rubber tube, to the top opening of the back limb. The requisite volume (150 cc.) of solution is now poured quickly into the pipette through the funnel, and the opening at the upper end of the back limb is closed, either with a small rubber stopper, or with one of the caoutchouc balloons sold specially for this purpose.

The front end of the pipette is now connected to the T-tube by a short length of rubber tubing. These joints are apt to prove troublesome, and the writer has found the following the best method of making them. Red rubber tube of special quality, with walls $\frac{1}{8}$ " thick is employed. A piece $1\frac{1}{4}$ inches long is wet internally, and is slipped entirely over the upper end of the absorption pipette. When the latter is placed in position in the stand, the short length of rubber tube is now gently worked up again by twisting, until it is half on the glass tube from the stop-cock; and half on the absorption pipette. The

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wetting of the internal walls facilitates this slipping motion. The ends of the two glass tubes should almost touch when the pipette is in position, in order to lessen the risk of loss of gas by permeation through the walls of the rubber tube. The rubber is then firmly bound in position by thin copper wire. When these joints have to be broken, it is most simple to cut through the rubber with a sharp, thin-bladed knife; since with the lapse of time the rubber sticks to the glass and the pipette may be broken in trying to remove it while the pipette is in the stand.

Making the Test.—After filling and connecting each of the absorption pipettes in the manner described, the water-bottle *I* is filled with a 20 per cent. solution of common salt, slightly acidified with HCl , and coloured pink with methyl orange, and is connected to the measuring burette by the rubber tubing *p*. By raising the bottle *I*, and opening the cock *S*, the air is expelled from the burette, and it is filled to the 100 cc. mark with brine. The cup *P* is then closed, the bottle is lowered, and the cock *g* is carefully opened in order to draw the KOH solution in the pipette *G* up to the containing mark *n*. The stopper *g* is of course removed during this operation. If by any mischance KOH solution gets into the tube above the mark *n*, or into the T-tube, it must be washed back into *G* by some of the brine from *M*. In the latter case, it will be advisable to remove the cock *G*, and wash it well with water; since otherwise it may stick fast and render a new T-piece necessary. After filling the absorption

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pipette G to the mark n with KOH solution, the stopper g is replaced; and the process is repeated with F and E respectively. In operations of this kind, it will be found most convenient to open the cock to the full extent, and to regulate the suction by pinching the rubber tube p between the finger and thumb; since by this means a more regular and slow approach of the liquids in the absorption pipettes, to the n mark on the capillary tube can be maintained. The absorption pipettes, when filled to this mark, should have about one inch of liquid in the back limb, and if caoutchouc balloons are employed for closing the openings E_1 , F_1 , G_1 , these should be removed and made quite empty. These balloons will then simply fill and empty, as the liquid in the pipettes rises and falls in the hinder limb, and all contact of the absorption liquid with the air will be avoided. The apparatus is now ready for use.

The sample of gas to be examined is drawn into the apparatus through the tube a and the U-tube b . The latter is filled with glass wool, and contains a little water in the bend, its purpose being to retain any particles of soot that may be present in the gas sample. The finger-pump K is provided in order that by aid of this and the three-way cock at S , the air in the U-tube b and connecting tube a may be displaced by the gases to be examined, before admitting the sample into the measuring burette. When the sample has been collected in a sample tube by the dry method (see p. 119), a 20 per cent. solution of common salt must be employed, to take the place

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of the 100 cc. of gas transferred to the Orsat apparatus. The simplest plan in effecting this transfer is to immerse the tube in a large beaker containing the brine, and after connecting the upper end to *a* to open the lower stop-cock, which must of course be kept under the surface of the liquid while the 100 cc. is drawn into *M*. This is effected by opening the stop-cock *S*, so that the gas has access into *i*, and by lowering the bottle *I*, and opening the clip *p*. Rather more than 100 cc. of the gas is drawn into *M*, the tube *p* is then pinched between the finger and thumb, and the cock at *S* is turned so that the connexion between *i* and the other outlets is closed. The bottle *I* is now raised, the pressure on *p* with the finger and thumb is released, and the imprisoned gas is reduced to 100 cc. by water pressure alone. The tube *p* is again pinched tight, close to the bottom of the measuring burette, and the cock *S* is turned so that the capillary tube *i* and measuring burette *M* are connected with the air for five seconds, the tube *k* and finger-pump *K* being removed for this purpose.

The 100 cc. of gas contained in *M* are now at atmospheric pressure, and the absorption can commence. *S* is closed as before, the bottle *I* is raised, and the cock *G* is opened, so that the sample passes into the first absorption pipette containing KOH. If stoppers are used to close *E*, *F*, and *G*, these must be removed as each pipette is brought into use; with caoutchouc balloons this is unnecessary. When the whole of the 100 cc. has passed into *G* it is allowed to remain ten seconds, and is then drawn back into

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M by lowering the bottle $\frac{1}{2}$. This transfer of the gas to *G* is repeated three times, and the absorbing liquid in *G* is then drawn up to *n*, the cock *g* is closed, and after levelling the brine in *I* and *M*, the volume of gas in the latter is read off. The diminution represents the percentage of CO_2 in the sample.

This process of transfer and absorption is now repeated in the pipettes *F* and *E*; and in a similar manner, by measuring the diminution in volume, the percentages of oxygen and carbon monoxide are obtained. After the last absorption the cock *S* is turned, so that the capillary tube *i* is in connexion with the air, and the residual gas, which is pure nitrogen, is expelled from the apparatus; this is then ready for a fresh test.

The Orsat-Lunge apparatus, when once in good working order, is fairly easy to manipulate, and yields accurate results; but the absorption pipettes are somewhat troublesome to clean and fill, and should the stop-cocks on the capillary tube stick tight, much time and energy may be fruitlessly lost in trying to loosen them.

The precautions necessary in using this apparatus are—

1. *Leakage*.—A measured volume of inert gas should be left for ten minutes, *under pressure* in the measuring burette and pipettes, at weekly intervals; any diminution in volume will, of course, indicate leakage. The residual gas from a previous test (which as pointed out above is almost pure nitrogen) is the best inert gas to employ for this test.

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2. *The glass stop-cocks* should be removed at intervals, the cocks and sockets thoroughly cleaned with soft paper, and after coating with a thin film of washed lard, or other suitable lubricant, they should be replaced. This treatment must also follow any mishap with the absorbing liquid in *G*, since KOH solution of 1.20 Sp. Gr. is noted for its power of causing two glass surfaces to bind fast.

3. *Volume Measurements.*—All measurements of volume in the burette *M* must be made with the brine at the same level within and without the burette, and the tube *p* at such times must be free from kinks. The water in the jacket tube around *M* must cover the whole of the burette, and must be changed occasionally.

4. *The Absorption Pipettes.*—These must be emptied, cleaned, and refilled with fresh absorbing solutions at regular intervals; the cuprous chloride solution being that which requires most frequent renewal. For the accurate determination of carbon monoxide in reasonable time, it is in fact necessary to have two cuprous chloride pipettes in use, and to employ the fresher solution for absorbing the last traces of the gas. Owing to the evolution of CO_2 from this solution, after it has been used for some time in the Orsat apparatus, the CO tests are always somewhat untrustworthy, unless made with freshly prepared cuprous chloride; and for works use it is not advisable to carry out this determination. The percentage of carbon monoxide in the waste gases can in such

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cases be fairly accurately estimated by use of the following formula—

$$x = 100 - (N + C + O),$$

where N equals the percentage of nitrogen, O equals the percentage of oxygen, and C equals the percentage of carbon dioxide by volume in the waste gases. For waste gases from fuels containing much hydrogen this formula yields incorrect results, however, since portion of the 20.8 per cent. of oxygen is used up in burning the hydrogen, and thus disappears from the volume of resultant gases owing to its condensation as water. This causes a variation of 2 per cent. or more in the volume of nitrogen, which in the above equation would then be 81.2 in place of 79.2. For a coal containing 4.80 per cent. H, 7.30 per cent. O, and 5 per cent. moisture, the calculated figures show that 81.5 per cent. N would be present in the flue gas.

RECORDING CO₂ APPARATUS.

A very large number of instruments for automatically determining and recording the percentage of carbon dioxide in the waste gases are now being manufactured and sold, and in the following pages the most useful of these will be illustrated and described.

The "Sarco" Recorder.—This apparatus, which is illustrated in Fig. 40, depends upon the absorption of CO₂ by a solution of potassium hydrate, an automatic arrangement being utilized for forcing a

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measured volume of the flue gases, at stated intervals of time, into the absorbing vessel. The volume measurements of the gas remaining after the CO_2 is absorbed are then transferred by a lever and arm attachment to a pen, which marks the result upon the recording paper carried on a revolving drum.

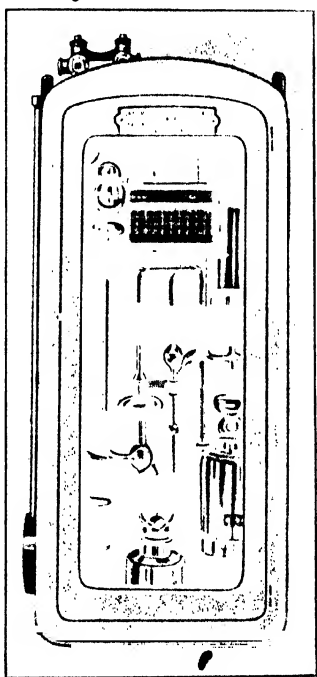


FIG. 40. THE "SARCO" CO_2 AUTOMATIC RECORDING APPARATUS.

Fig. 41 shows the diagram obtained over twelve hours with this apparatus, the vertical lines representing the volumes of unabsorbed gas; and the test being made ten times in the hour, or every six

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minutes. The gases are drawn from the flues by independently worked suction pumps, so that a large sample is available for each test.

The "Sarco" apparatus is now in use in a very large number of works in this country and on the Continent. If carefully used, and kept in good order, it yields a very valuable check upon the firing of the boiler plant; and by its aid, considerable economies in fuel can be effected. The results obtained, however, with the "Sarco" apparatus, should be checked by independent CO_2 tests at

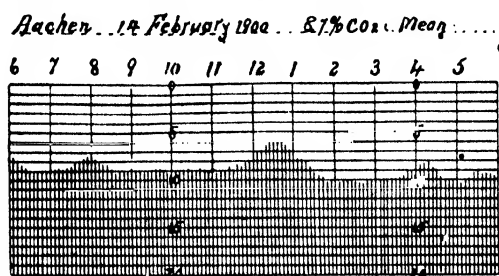


FIG. 41. RECORD OBTAINED OVER TWELVE HOURS WITH THE "SARCO" CO_2 RECORDER.

stated intervals; since an error in the percentage of CO_2 may otherwise be perpetuated through a whole series of the automatic records. The caustic potash solution also requires frequent change for the maintenance of accuracy; and the apparatus could hardly be left to the charge of an ordinary boiler engineer.

The Simmance and Abady Recorder.—This Recorder is illustrated in Fig. 42, and like the Sarco apparatus is dependent upon the absorption of the CO_2 by

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caustic potash solution. About 600 cubic centimetres of the flue-gases are drawn from the flue at definite intervals of time, by means of an automatic sampler which is operated by water, and a measured portion

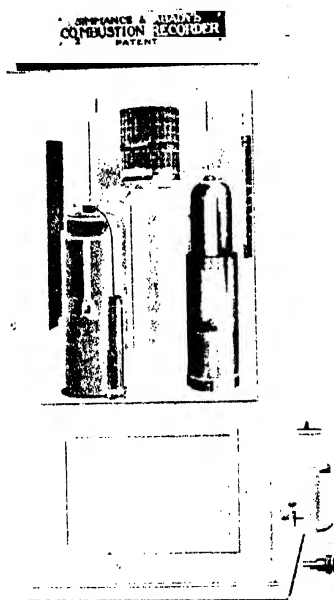


FIG. 42. SIMMANCE AND ABADY RECORDER.

of this volume is employed for each test in that portion of the apparatus called the "analyser."

When the flue-gas has been transferred from the "extractor" into the "analyser," the CO_2 is absorbed, and owing to such absorption, the analyser

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bell will not rise to its full height. It is allowed to work automatically and to rise as far as it will where it remains for a few seconds, and then drops a little as the heat of the chemical combination disperses and the absorption is completed. At this point a pen descends, and marks downwards from the zero on the chart to the position of the analyser bell. The percentage of CO_2 in the gas is thus automatically recorded. The bell then discharges its residual gas, and a new charge of gas is brought forward to be dealt with in exactly the same way, the whole of the operations taking place automatically and the motive force being supplied by the dripping water.

The Uehling Gas-Composimeter.—The Uehling apparatus for determining and recording the amount of CO_2 in flue-gases, is based upon the law governing the flow of gas through two small apertures.

Two gas-containing vessels of different capacities are placed in connexion with a steam-jet aspirator, and with the flue. The apertures connecting the smaller vessel with the other, and the second or larger vessel with the flue, are small and of equal size. When the aspirator is set to work, a partial vacuum is produced in both vessels, consequent upon the fact that gas is being drawn out of them more quickly than it can enter; and the vacuum as measured by manometers attached to each vessel is found to be twice as great in the smaller, as in the larger vessel. If now the gas passing through the larger vessel be submitted to the action of a solvent which absorbs and withdraws one of its constituents, the vacuum

EXAMINATION OF THE WASTE GASES

in the second chamber or vessel, will be increased, and the difference between the partial vacuum in the two vessels will be diminished in like ratio. The absorption of CO_2 from furnace gases by caustic



FIG. 43. UEHLING RECORDING APPARATUS.

potash can therefore be utilized, to cause differences in the pressure ratio in the two gas vessels; and by proper calibration a means for ascertaining the percentage of CO_2 in the furnace gases is obtained. To embody this principle in a practical apparatus the following conditions must be fulfilled.—(1). The gas

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must be brought into the apparatus under a constant tension and must be drawn through the two apertures with a continuous and uniform suction. (2) Both apertures must be located in a part of the apparatus which is maintained at a constant temperature. (3) Provision must be made for keeping these apertures perfectly clean. (4) The larger chamber must be made perfectly gas-tight. (5) The constituent to be absorbed must be entirely removed while the gas is passing through this part of the apparatus. Further details of this CO_2 recording apparatus will be found in *Power*, June 1907.

The Bi-Meter CO_2 Recorder.—This is a new form of CO_2 Recorder which has only recently been introduced. The simplicity of its principle and construction, and the possible extension of the principles upon which it is based to include the estimation of oxygen, render this form of Recorder of considerable interest to fuel-users.

The principle of the apparatus is the measurement of the volume of flue-gas by accurate gas meters, before and after its passage through an absorbing chamber containing lime and shavings, the gas being brought to the same temperature by water-cooling before each measurement. The differential reading of the two gas meters, is then a measurement of the percentage of CO_2 present, and is recorded on a chart in the usual manner. Fig. 44 shows this apparatus. It is evident that by adding an absorbent for oxygen the apparatus could be greatly increased in value, without adding greatly to its cost.

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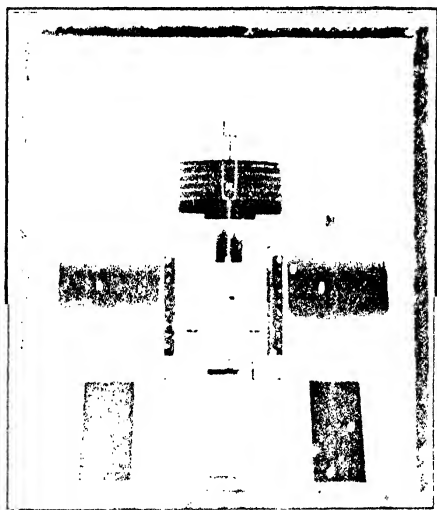
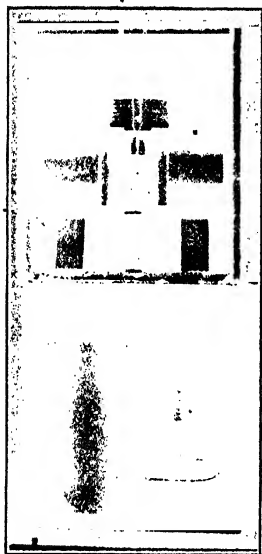


FIG. 44. CAMBRIDGE BI-METER RECORDER.

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Other Recorders which have received practical trial are, the Arndt and the Krell. Both are gravimetric in principle, though of different construction, and the latter suffers from the defect that the records require photographic development before they are available for reference. This defect has tended to discourage its adoption for practical boiler work.

All forms of automatic testing apparatus suffer from the disadvantage that they fail to give any indication of the volumes of carbon monoxide and unburnt hydrocarbon gases passing away with the waste gases, and that they require regular and skilled attention to keep them in working order. When these limitations are fully understood and allowed for, the use of CO₂ recording apparatus is of great service in checking and controlling the work of the firemen.

As regards the installation of automatic testing apparatus, no pipes smaller than $\frac{3}{4}$ " should be employed; all bends should be formed with T-pieces and a screwed plug for cleaning-out purposes, and a steam connexion should be arranged for, by which high-pressure steam can be blown through the whole system of pipes, in order to clear out accumulated deposits of rust and dirt. Condensed moisture should be regularly removed from the pipes, by setting them with a fall to a catch-box or steam trap near the testing apparatus.

5. THE SIGNIFICANCE OF THE GAS TEST RESULTS

All heat passing away with the waste gases to the chimney is lost from the fuel-user's point of view,

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and therefore the highest efficiency can only be obtained by reducing the volume and the temperature of these gases to the lowest limit consistent with proper combustion of the fuel in the furnace. The temperature observations are made as already described in section B of this Chapter ; the requisite check upon the volume of the waste gases is furnished by the CO_2 tests, carried out as described in Section C. 1-4.

Air is composed, in round numbers, of 21 per cent. oxygen and 79 per cent. nitrogen by volume, or 23 per cent. O and 77 per cent. N by weight. When coke is burnt in the exact volume of air requisite to produce carbon dioxide gas, the latter will occupy the same volume as the oxygen from which it has been formed ; and perfect combustion under such conditions yields a gas containing 21 per cent. CO_2 and 79 per cent. nitrogen. Under proper conditions this percentage can be approached in actual practice, with coke or anthracite combustion furnaces. When bituminous coal is burned, the hydrogen of the hydrocarbons carries off some of the oxygen to form water, and the theoretical CO_2 percentage that can be obtained with such fuel is about 19 per cent. ; while 16 per cent. represents the highest obtainable in actual practice.

Percentages of CO_2 below this maximum indicate that more air is being passed through the furnaces than is required for the combustion process ; and the diminished CO_2 percentage is the measure of this excess air. Thus 15 per cent. CO_2 with bitu-

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minous fuel represents $\frac{1.9}{1.5} = 1.27$ times the requisite volume of air, or a 27 per cent. excess ; while 8 per cent. CO_2 represents $\frac{1.9}{1.5} = 2.37$ times the requisite volume, or 137 per cent. excess.

The temperature at which the exit gases pass into the chimney next requires consideration. Since the draught of the chimney depends upon the specific gravity of the waste gases in relation to that of the surrounding atmosphere, and this, again, depends upon their temperature, it is obvious that there is a point below which heat cannot be abstracted from the flue gases without endangering the draught, and therefore the efficiency, of the whole boiler installation. This point, for chimneys of normal height and capacity, is about 400°F. (205°C.), and it is therefore unwise to cool the exit gases below this temperature. Where artificial draft is employed (either forced or induced) this difficulty has not to be faced ; and in such cases there is no objection to abstracting all the heat possible from the flue gases, before they pass into the atmosphere.

The Authors believe that in time artificial draught will be much more widely used than at present, for boiler and furnace work. The difference in cost between natural and artificial draught (if the interest on capital outlay and loss of heat, necessitated by a tall brick chimney, be properly debited to the natural draught account) is much less than is generally recognized by boiler engineers. Moreover, the draught obtained from chimneys, however tall and large, is excessively variable, and is too dependent

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upon the wind and state of the atmosphere, to be well adapted for the scientific working of large boiler plants. The change from natural to artificial draught which is now occurring in the control of the lead chamber process, for manufacture of sulphuric acid, is indicative of what may occur at a later date, in the more scientifically managed steam generating plants of this country.

However, at present, natural draught is usually employed, and a certain loss of heat in the exit gases is absolutely necessary. This necessary loss can be ascertained by the following calculations.

One pound in weight of average fuel requires theoretically about 12 pounds of air for its complete combustion, and yields about 13 pounds of waste gases. The specific heat of these waste gases varies according to the percentage of CO_2 and H_2O they contain, and for a gas containing 15 per cent. CO_2 Poole gives the specific heat as $\cdot 323$. But, as already pointed out, 15 per cent. CO_2 represents a 27 per cent. excess of air by volume in the waste gases, and the total weight in this case will therefore be increased by $12 \times \cdot 27 = 3\cdot 2$ pounds, or from 13 to 16.2 pounds.

Assuming that these 16.2 pounds of waste gases pass to the chimney with a final temperature of 350°F . (or 176°C .), the heat loss will amount to $16\cdot 2 \times \cdot 323 \times 160 = 837$ centigrade units; or to 11.1 per cent. of the total heat value of the coal, when this is equivalent to 7,500 centigrade units. This then represents the heat necessary for creation of the chimney draught. Its loss can never be avoided, and

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converted into *£ s. d.* : it must be regarded as the price paid for so-called "natural draught."

Supposing, now, that in place of a temperature of 350°F., the waste gases pass to the chimney at 656°F. (346°C.), the usual temperature when economizers are not installed. The loss then becomes $16.2 \times .323 \times 330 = 1,726$ centigrade units, equal to 23 per cent. of the total heating value of the fuel. The loss grows still larger when, in place of 15 per cent. CO₂ being found in the exit gases, only 8 per cent. CO₂ are present. The excess of air is now equal to 137 per cent., and the weight of waste gases becomes 29.4 pounds per pound of fuel burnt. The specific heat of exit gases containing only 8 per cent. CO₂, according to Poole, is .316, and the loss therefore rises to $29.4 \times .316 \times 330 = 3,066$ centigrade units. This is equal to 40 per cent. of the heat value of the original fuel.

These figures and calculations show the great importance of the heat losses in the waste gases, and the necessity for gas analysis as a check upon the volume of air passing through the boiler furnaces.

In Table III of the Appendix, the percentage of fuel loss arising from the heat losses in the waste gases has been presented in tabular form, for various temperatures and percentages of CO₂.

The specific heats used in these calculations have been calculated on the assumption that a bituminous fuel containing 57 per cent. fixed carbon, 30 per cent. volatile matter, and 13 per cent. ash, has been utilized in the boiler furnace, and that the calorime-

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tric value of this fuel is 7,500 centigrade units (equal to 13,500 B.T.H.U.). The Sp. Heats obtained are much lower than those given by Poole, and it is evident that further experimental work is required on this subject.

It has also been assumed that this fuel when fired contained 5 per cent. moisture. Since the latent heat of steam is equal to 536 calories, a further loss of heat is due to the evaporation and specific heat of the aqueous vapour, produced from the burning fuel. In the case under consideration, this will amount to $(636 \times .05) + (.479 \times .65 \times 330) = 39.7$ centigrade units, .479 being taken as the specific heat of aqueous vapour under constant pressure.

The analysis of the waste gases may also indicate a further source of loss. When boilers are heavily worked, and draught is deficient, carbon monoxide may be found in the waste gases. This is especially the case when smoke is being produced—that is, when fresh coal is being thrown on the fires. Under such conditions, the carbon and hydrocarbons do not meet at once with sufficient oxygen to convert the carbon into carbon dioxide, and unless a secondary air supply be provided, the monoxide is produced. Reference was made in Chapter I (see p. 35) to the great difference in heat values of carbon burnt to CO, and burnt to CO₂. The difference in centigrade units is 5,684, and when 1 pound of ordinary fuel containing 72.6 per cent. carbon is burnt with deficient air supply, the loss of heat from this cause amounts to $5,684 \times .726 = 4,126$ centigrade units,

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or to 55 per cent. of the total heat value of the fuel. Even under normal working conditions, a small percentage of carbon monoxide will often be present in the gases just above the fires ; but if the secondary air supply, which ought to come in at the bridge, or door, is properly regulated, the oxygen necessary to convert this monoxide into dioxide will be provided at this point, and the final stage of the combustion of the carbon will be completed without loss of heat.

The tendency in practice is, however, to work with a large excess of air, and the heat losses in actual practice are due much more to the heat mechanically carried away by waste gases, than to imperfect combustion and formation of carbon monoxide.

The heat losses due to these causes in boiler installations, as usually worked, are much greater than is generally recognized by boiler engineers ; and there is no doubt that in many cases these losses rise to over 30 per cent. of the total heating value of the fuel. Even when economizers have been installed there is still need for a careful check upon the composition of the waste gases ; for although the temperature cannot be reduced below 350°F. (175°C.) the volume of the gases by careful work may be approached to the limit represented by 15 per cent. CO_2 , which it has been shown, represents the minimum loss, and is equal to 11.1 per cent. of the total heat value of the fuel.

Supposing, now, that in place of 15 per cent. CO_2 , only 8 per cent. are present in the waste gases. The heat wasted under these conditions rises to

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$29.4 \times .316 \times 160 = 1.498$ units, or to 20 per cent. of the fuel value, and the loss is practically doubled.¹ Boiler engineers must not therefore assume that the possession of an economizer plant relieves them from the necessity of keeping a careful eye to the composition of the exit gases.

In order to ascertain the best working conditions for each boiler, tests should be made at 15-minute intervals with the Honigman apparatus, over a period of two or three hours under normal working conditions; and the best position of the dampers and other air regulating devices should be definitely settled for each stage of the firing process. Permanent marks should then be placed on the dampers and air slides, to render it easy for the fireman to renew these positions as required during his work. The results can then be checked, by connecting one of the recording instruments to the flues of this boiler, and by noting the CO₂ percentages over a 24-hours' run, or a week's work. As already stated, perfect combustion and maximum efficiency can only be attained when sufficient draught is provided; and this must be the first matter to receive attention if the original test results are below the maximum desired. Given adequate draught, it is simply a matter of careful testing and damper regulation to obtain from each boiler the maximum efficiency. If the interest of the stokers be aroused in the subject, by paying them a weekly premium, based on the CO₂ test results, the improved "experimental"

¹ See p. 149 for explanation of these factors.

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results will be rendered permanent and will soon be made manifest in a reduced consumption of fuel for the maintenance of steam. In the absence of such inducement to better work, it is to be feared that the results obtained will remain "experimental."

The highest efficiency is, however, unattainable if the boilers are being overworked; and one of the first steps towards improvement in many steam-raising plants in this country, is that an addition of between 20 per cent. and 30 per cent. should be made to the number of boilers installed, or that a system of forced draught should be adopted for raising the evaporative capacity of the existing installation.

It must be stated here, however, that adding to the number of boilers is not in every case a cure for smoke, as so many smoke inspectors appear to think. Smoke is in some cases the result of too much grate surface combined with lack of ashpit dampers as previously explained.

6. PRACTICAL DETAILS OF BONUS SCHEMES

A system of bonus payments to the firemen is, as stated above, a *sine qua non* if high efficiencies are to be attained regularly in boiler working, and therefore it has been thought wise by the Authors to add some details of two methods of making bonus payments which are now in practical operation in England and Germany.

EXAMINATION OF THE WASTE GASES

In the first case, that of one of the largest English Municipal Electric Light and Power Stations, the bonus is based upon the coal consumption per B.O.T. Unit (K. W. hr.) generated; when this is below a fixed limit the foremen-stokers, stokers and trimmers all receive a bonus addition of 10 per cent. to their wages.

The standard of coal consumption is varied from time to time, according to the class of fuel used; and the past year's average coal consumption of the Station. When the system was first started the standard was 5 lbs. per B.O.T. Unit, this has since been reduced to $4\frac{1}{2}$ lbs., and then to 4 lbs., and it now stands at 3 lbs. per B.O.T. Unit. The reduction is largely due to the adoption of this system of payment.

The second example is drawn from Hamburg, and is used in connexion with the efforts of the officers of the Hamburg Smoke Abatement Society, to promote good stoking and a low fuel consumption, in the steam-raising plants of the members of that Society. The bonus scheme in this case is based upon the average CO_2 tests during each stoker's shift of duty, the sampling and testing apparatus having been already described in Section C 3 of this chapter (p 123).

The percentage of unburned hydrocarbons and of carbon monoxide in the exit gases, is calculated from the total percentage of carbon dioxide and oxygen, the total percentage of these two constituents, when perfect combustion has occurred, fluctuating between 19.0 per cent. and 19.5 per cent., according to the kind of coal used.

SMOKE PREVENTION AND FUEL ECONOMY

The following tables show the working of the method in practice, with the basis upon which the bonus for good work and fines for bad work, are calculated :—

Date.	Time.	Firemen.	Boiler No.	Average per cent. of CO ₂	Average per cent. CO ₂ and O.
June 22, 1907.	6.30 a.m. to 5.30 p.m.	Muller	1 and 2	16.3	19.4
June 22 and 23	6.0 p.m. to 6.30 a.m.	Lange	2	11.0	19.5

BONUS TABLE FOR GOOD PERCENTAGES OF CO₂

Fuel burnt; about 7,000 kilogrammes in twelve hours, costing sixteen marks per 1,000 kilogrammes.

Temperature of the exit gases; 200° to 320° Centigrade.

Average per cent. of CO ₂ .	Fuel Saved; Kilogrammes.	Value of Fuel Saved; Marks.	Bonus Addition to Wages; Marks.
8.0	—	—	—
8.5	105	2.60	.15
9.0	360	5.75	.30
9.5	490	7.85	.40
10.0	645	10.30	.50
10.5	740	11.85	.60
11.0	900	14.45	.70
11.5	1,005	16.20	.80
12.0	1,120	17.95	.90
13.0	1,200	20.20	1.00

FINES TABLE FOR INCOMPLETE COMBUSTION

Average Percentage of CO ₂ and Oxygen. ¹	Fuel Burnt Unnecessarily; Kilogrammes.	Value of Fuel Wasted; Marks.	Fine; Marks.
19.4	—	—	—
16.0	80	1.25	.10
18.7	225	3.10	.15
18.4	315	5.00	.25
18.1	460	7.35	.35
17.8	610	9.75	.50

¹ NOTE.—The average percentage of CO₂ and O is an index of the amount of carbon monoxide and unburnt hydrocarbons passing away with the waste gases (see p. 439).

EXAMINATION OF THE WASTE GASES

Similar tables can be worked out for each boiler installation, taking into account the class of fuel and the amount used per shift. With the aid of these tables the labour involved in calculating the bonus (or fine) for each stoker's work is reduced to a minimum, and the men are given a very real incentive to saving fuel and preventing waste. The system is stated to yield most satisfactory results.

CHAPTER V¹

The Legal Position and the Work of Voluntary Agencies

I. THE PRESENT STATE OF THE LAW IN LONDON AND THE PROVINCES AND THE EFFECTS OF SMOKE PROSECUTIONS

PROSECUTIONS for excessive smoke emission are based, in England, in almost all cases, on the Provisions of the Public Health Act of 1875, or upon similar Provisions in local Acts. The London Public Health Act of 1891 is representative of the latter, and contains clauses dealing with excessive smoke emission. Proceedings within the Metropolitan area, are always taken under this Act.

When the emission of smoke can be proved to be the cause of either injury to health or to public and private property, proceedings may, it is true, be taken under the common law, but it has been found difficult in the past to prove the existence of an actionable nuisance, and prosecutions under the common law were too often unsuccessful and have now been almost entirely dropped.

Section 91, Sub-section 8, of the Public Health Act of 1875 enacts that "any chimney not being

¹ The first portion of this chapter is based upon an article contributed to *The Nineteenth Century and After* for October, 1911.

LEGAL POSITION AND VOLUNTARY AGENCIES

the chimney of a private dwelling house sending forth black smoke in such quantity as to be a nuisance, shall be deemed to be a nuisance liable to be dealt with summarily in manner provided by this Act," and Section 92 of the same Act imposes upon the local authority, the duty of inspecting the districts for which they are responsible, and of enforcing the Provisions of this Act as regards nuisance arising from smoke. Section 106 provides for the coercion of defaulting local authorities in this matter, by the local Government Board.

The provisions of the London Public Health Act of 1891, and of the other local Acts, under which proceedings are taken in Birmingham, Glasgow, Liverpool and Leeds and a few other large towns, are practically the same as those of the Act of 1875. Section 23 of the London Act imposes cumulative fines for every conviction on any person who "being the owner or occupier of the premises, or being a foreman or other person employed by such owner or occupier, (a) uses any furnace 'employed in trade' which is not constructed so as to consume or burn the smoke arising therefrom, or (b) so negligently uses any such furnace as that the smoke arising therefrom is not effectually consumed or burnt, or (c) carries on any trade or business which occasions any noxious or offensive effluvia, or otherwise annoys the neighbourhood or inhabitants without using the best practicable means for preventing or counteracting such effluvia or other annoyance." Section 24 enacts that "any chimney (not being the chimney

SMOKE PREVENTION AND FUEL ECONOMY

of a private dwelling house) sending forth black smoke in such quantity as to be a nuisance" shall be deemed a nuisance liable to be summarily dealt with under this Act.

By a decision of the Courts in 1903, it was held that London Club premises were not to be regarded as private dwelling houses, and were not to be exempt from the operation of the Act. As regards the powers of provincial cities, the following is the Section dealing with *Smoke* in the Glasgow Police Act of 1892, Section XXXI. "Every person who so uses, causes, permits, or suffers to be used, any furnace or fire within the city (except a household fire) so that smoke issues therefrom, unless he proves that he has used the best practicable means for preventing smoke, and carefully attended to, and managed such furnace or fire so as to prevent as far as possible smoke issuing therefrom, shall be liable for the first offence to a penalty not exceeding forty shillings, and for the second or any subsequent offence (if committed within twelve months of the immediately previous conviction) to a penalty not exceeding five pounds."

This being the legal position as regards the nuisance arising from excessive smoke emission, it is of interest to see what success has attended the operation of these Acts in the past. In a large number of towns and cities where manufacturing operations are carried on, some attempt has been made to enforce the existing law, and special inspectors have been appointed to watch the Factory chimneys and

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to report when excessive smoke emission occurs. Glasgow, which is most energetic in this matter, has five smoke inspectors; Manchester has four and Liverpool three.

In London, the Coal Smoke Abatement Society have their own paid inspector for this work; while similar organizations in other cities also assist the local authorities by reporting the cases of excessive smoke emission when they occur. But it is one thing to report, and another to obtain convictions under the Acts, and only a very small proportion of the cases brought before the magistrates are successful, or result in the imposition of a fine. The offending party generally pleads (1) that the inspector was mistaken and that his chimney was not the offending one; (2) that the excessive smoke emission was due to a temporary breakdown; (3) that he has spent or is about to spend a large sum upon some patent smoke consuming device warranted by the inventor to suppress all smoke; and on one or other of these pleas he generally succeeds in escaping the imposition of a fine. Even when a fine is imposed, it is usually so light, that it is cheaper to pay it than to incur any expenditure upon alterations or improvements of the plant. The power to impose cumulative fines for repeated offences under the local Acts, is still more rarely exercised even when it exists. At Glasgow, each twelve months is treated as a closed period, and the offending party starts with a clear slate as regards previous convictions when this period has expired.

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Further, in too many towns and centres of manufacturing industry, the provisions of the Public Health Act of 1875, in so far as they relate to the nuisance arising from smoke are never enforced. Those who ought to set the Act in operation are themselves manufacturers, and have no desire to annoy and worry their fellow-manufacturers (even if blameless themselves) and Sections 91 and 92 of the 1875 Act in their districts are practically a dead letter. Stipendiary Magistrates are, as a rule, equally lenient towards offenders under the Acts, due to the fact that most of them have no scientific knowledge, and have not the faintest idea what is, and what is not, possible with a boiler furnace.

In London, a further difficulty has been created in the path of those who are charged with the duty of enforcing the provisions of the Public Health (London) Act of 1891, by the decision of Mr. Curtis Bennett in 1908, in the Lots Road Electrical Generating Station case. This Station possesses four huge chimney shafts each 19 feet in diameter, and it was urged successfully by the defence that the smoke emitted from these chimneys only appeared "black" because of its great depth and volume, and that it would have appeared much lighter in colour, if emitted from chimneys of half the diameter. Since the decision of Mr. Curtis Bennett in favour of the defendant Company, there have been exceedingly few prosecutions for nuisance arising from smoke within the Metropolitan area, and there is general dissatisfaction expressed with the state of the law.

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upon the subject. This discontent has found expression in the attempt of the London County Council in its General Powers Bill of 1910 to obtain further powers in relation to the nuisance arising from smoke emission, and in a Deputation representing 19 municipalities and public associations which interviewed the President of the Local Government Board in June 1910, and urged that the smoke clauses of the London Public Health Act of 1891 (as amended in 1910) should be made applicable to the whole country.

The chief modification in the London Public Health Act of 1891, proposed by the London County Council was the deletion of the word "*black*" from Section 24, which would then read:—"Any chimney, not being the chimney of a private dwelling house, sending forth smoke in such quantity as to be a nuisance shall be deemed a nuisance" etc., etc.

It was stated in support of this change, that until this alteration was made, no smoke prosecution in the Metropolis could succeed, for the offending parties could always refer to Mr. Curtis Bennett's decision and plead, that if the smoke had been emitted from double the number of smaller chimneys, it would have appeared grey in colour.

The Select Committee of the House of Commons charged with the consideration of this Bill decided on June 28, 1910, to retain the word "*black*" in Section 24 of the Act of 1891. It is evident, however, that the controversy is not yet ended, and when the London County Council's General Powers Bill

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for 1912 is framed, the attempt to obtain some amendment of the wording of Clause 24 is almost certain to be renewed.

The present state of the law with regard to the nuisance arising from smoke emission in London and the provinces is therefore far from settled, and prosecutions under the 1875 and 1891 Acts are rarely obtained. In those cases in which the proceedings have been successful, the fines imposed have been inadequate. Many of those interested in Smoke Abatement are beginning to doubt whether further effort in this direction is desirable or necessary, and to ask whether better progress could not be obtained, by concentrating effort and attention upon those voluntary methods of dealing with the evil which will now be discussed.

2. THE WORK OF VOLUNTARY AGENCIES

The voluntary agencies which have been called into existence during the last few years for the purpose of promoting smoke abatement, may be divided into two broad classes.

In the first of these may be grouped all the societies which exist merely for the purpose of calling attention to the evils arising from black smoke, or of reporting offenders under the present law; while the societies, which have more educational and practical aims, and whose members are drawn chiefly from the manufacturers and actual consumers of the fuel, may be gathered into Class II. The

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value of the work carried out by these different societies and organizations, can be judged most satisfactorily by examining their latest Reports.

The London Coal Smoke Abatement Society is the most representative of the Societies in Class I. This Society was founded in the year 1899, and is therefore now in the twelfth year of its existence. The Society's chief work, during the past eleven years, has been to call the attention of Londoners to the dirt and damage caused by smoke within the Metropolis, and to assist the authorities by reporting offenders under the London Public Health Act of 1891. The Society maintains at present one inspector, who reports to the Committee the cases of excessive smoke emission, as they arise, and the Committee in their turn, after examining the evidence, pass on the reports to the various local councils and authorities concerned. During the year 1910, 1,094 cases of excessive smoke emission were reported by the Society's inspector; in the majority of cases these Reports formed the basis of complaints to the borough councils and other local authorities. The following extract from the 1909 Report shows the difficulties and limitations of the Society's work in this direction :—

“ There are, it is true, a limited number of Metropolitan authorities such as the Southwark Borough Council, which still fail to enforce the provisions of the Public Health (London) Act, 1891, under the mistaken impression that if they insist upon the abatement of smoke nuisances, they unfairly harass

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trade. They decline to recognize the accumulated evidence by the Society and by independent investigators that it is possible to get rid of black smoke nuisances without ultimate loss, and, indeed, generally with much profit to the manufacturer. And they confine their activities to the issue to the offenders of formal complaints, or even friendly letters, mildly urging that steps should be adopted to remove the nuisance.

“Under such circumstances no improvement can be expected. Where (as for example in Westminster or in the City of London) the Council has resolutely insisted upon the observance of the law, a remarkable improvement has been effected.

“But, in the view of the Committee, no further step forward can be anticipated until the law has been simplified, and the powers of the London County Council extended.

“It has been frequently pointed out by the Coal Smoke Abatement Society that the factories which now cause London the greatest inconvenience from smoke-polluted air, are those situate on the verge of the Metropolis. Over these works the London County Council has no jurisdiction, and whenever the wind sets in from the east, it brings with it the smoke from scores of factories, and in winter time greatly adds to the severity and density of fogs.

“Although this is admittedly the case, the Society cannot induce the sanitary authorities concerned to take any effective steps to abate the nuisance.

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In the case of West Ham about 3,600 complaints have been made by the Society to the Corporation. Not a single prosecution has ensued. The nuisances may be observed at any time and by any one, and the accuracy of the Society's complaints can be readily tested. Under such circumstances it is competent for the Local Government Board to intervene, but that department has once more declined to move or even to send an inspector to check the Society's observations, though pressed in Parliament to do so. At Chiswick a similar state of affairs exists in connexion with an Electricity Generating Station ; and on the banks of the Thames, between Woolwich and Gravesend, a large number of factories exist which are constant offenders. Notwithstanding this the local authorities fail to move, possibly because representatives of some of the offending firms are known to be members of the councils whose express duty it is to suppress black smoke nuisances.

• “ Under these circumstances the Committee are of opinion that nothing will be done to abate these nuisances until the London County Council is empowered by Parliament to take proceedings in the case of smoke nuisances, which, though arising outside the area under the Council's control, pollute the atmosphere of the Metropolis.”

• The Coal Smoke Abatement Society therefore supported the London County Council in its efforts to obtain extension of its powers in relation to the nuisance and damage arising from smoke, and its

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President (Sir William Richmond) has expressed in public his profound disappointment that the proposed alteration of Section 24 of the 1891 Act, was not accepted in June 1910 by the Parliamentary Committee.

The London Society's more practical work has been the joint promotion with the Royal Sanitary Institute, of a very successful Exhibition of Smoke Prevention Appliances, and a three days' Conference on Smoke Abatement, at the Vincent Square Hall in Westminster during December 1905; and more recently of courses of lectures to stokers and firemen, at the Borough Polytechnic. These lectures were delivered for two winters, by Mr. W. H. Booth, F.G.S., and were very largely attended.

The *Hamburg Smoke Abatement Society*, or to give the German title, the *Vereins für Feuerungs betrieb und Rauchbekämpfung in Hamburg*, may be selected as chief representative of the Societies of Class II., for it is a voluntary association of fuel users with works or factories located in and around the city of Hamburg. The Society was started in the year 1902 by a few Hamburg manufacturers, who were convinced that by more scientific control of their steam-raising plant, they could save coal and reduce smoke.

The Society has achieved a striking success, and at the end of 1908 there were 365 subscribing members on its register, and 1,207 boilers, with 155 other appliances, under the control of its engineers. The Society is managed by a strong Committee of

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manufacturers. The technical work is undertaken by a staff of five engineers and four instructors for firemen; these devote the whole of their time to the supervision of the steam-raising and heating plant of the members. Fuel savings of between ten and fifteen per cent. are of common occurrence in the past records of this Society's work, and the annual Reports form a most valuable contribution to the literature of smoke prevention and fuel economy.

The civic authorities of Hamburg have recognized the value of the Society's work by placing the whole of the municipal steam-raising and heating plant under its control.

The latest accession is the Hamburg Bakers' Guild. The baking ovens of the majority of bakers in the city of Hamburg are now worked and fired in accordance with the instructions of the expert staff of the Verein.

During 1909 the emission of smoke from the steamships lying in the river and docks claimed the Society's attention, and it is stated that some improvement may be expected to follow from the special study made of this branch of the problem.

In addition to their regular work of testing and supervising the efficiency of the steam-raising plant of the members of the Society, the engineering staff have carried out special investigations relating to—mechanical firing; the purchase of fuel on a heat-unit basis; the advantages of Bonus payments to firemen; and to other matters of great interest to fuel users.

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The practical training and supervision of stokers, which has been undertaken by the Society since its formation and forms one of the most important and useful branches of its work, has been continued with success during the last few years. Four instructors are specially retained for this duty.

THE SMOKE ABATEMENT LEAGUE OF GREAT BRITAIN

An exhibition of Smoke Abatement Appliances, and a Conference upon Smoke Abatement held in Sheffield in March 1909, led to the formation of a new organization with the above title, and three branches of this League have been started—in Glasgow, Manchester and Sheffield.

The Glasgow and West of Scotland Branch of this League is the most active, and combines to some extent the objects of both the London and Hamburg Societies. These are set forth in its Constitution as follows :—

- (a) To promote such consolidation of, and improvement in legislation, as would secure Smoke Abatement, and to join with other branches throughout the country, in furthering the objects of the League.
- (b) To take steps to institute lectures and spread information among the public by pamphlets and leaflets, and generally to carry out an active propaganda against the smoke nuisance.
- (c) To approach the Glasgow and West of Scotland

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Technical College and other educational institutions regarding the establishment of lectures on combustion and furnace management for firemen and boiler attendants, with a view to the granting by the League of certificates of competency.

No time has been lost by this branch Society (which was only instituted on February 2, 1910), in commencing an active educational propaganda in Glasgow upon the subject of Smoke Abatement, on the lines indicated in the "objects" of the Society as set out above.

Two courses of evening Lectures were arranged for the winter months of 1910-11, the first intended to teach working boiler engineers and firemen the scientific principles underlying their craft, and the second directed towards the education of their superiors—the manufacturers, ship-owners, and the general public.

The series of Lectures for firemen, consisted of five similar courses of twelve lectures each, delivered by the Glasgow Municipal Sanitary Officers and Smoke Inspectors, in different centres of the working class portion of the city, a fee of 5s. being charged for the course. The education authorities of Glasgow and Govan granted the use of suitably situated elementary schools for these lectures, and 186 firemen and engineers registered their names as students at one or other of the various centres. In the majority of cases the employers paid the fee, and urged the men to attend regularly.

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The series of nine lectures for the general public were free, and were made attractive by the aid of limelight views and experiments. They were delivered in the large Hall of the Technical School by several gentlemen connected with the Health and Medical Departments of the University and City, and covered such objects as,—

“The Black Smoke Problem;” “The Necessity for Pure Air;” “The Chemistry of Combustion;” “How to fire Steam-Boilers without Smoke,” etc., etc.

Appendix

I. PATENT ABSTRACTS

INTRODUCTORY NOTE

THE Authors have not attempted in this section to deal with all the Patent literature of Smoke Prevention. A selection has simply been made of the Patents granted in recent years in England, Germany and America, for fuel-consuming appliances designed to promote more perfect combustion.

The English Patents chosen deal chiefly with devices for supplying secondary air ; the German, with improved methods of grate or furnace construction ; and the American, with improved forms of mechanical or automatic stoking appliances. The numerous English mechanical stoking appliances have not been specially described in this section, because the general principles underlying their construction have been dealt with in Chapter II ; and these mechanical stokers are now in such general use, and so widely known, that their special description at this date, in a book intended for practical engineers, is somewhat superfluous.

The Authors make little comment upon the value or validity of the various Patents described in this

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section of their work, but the information as to the correct conditions for perfect fuel combustion, given in Chapters I, II and III of this book, will enable readers themselves to judge of the value, or otherwise, of these inventions.

A. ENGLISH PATENTS

No. 19,631 OF 1900

A Patent granted to GREEN & HOWE for "IMPROVEMENTS CONNECTED WITH THE COMBUSTION

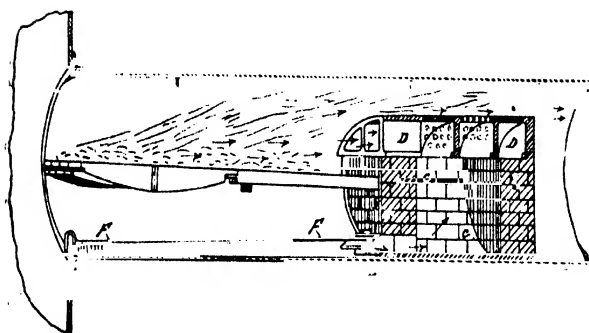


FIG. 45. THE GREEN & HOWE BRIDGE CONSTRUCTION.

OF FUEL IN FURNACES." The essential feature of the Green apparatus is that of a bridge supply of hot air. The supply of air is under control, and can be regulated by the fireman, according to the body of flame and smoke passing from the furnace grate. Fig. 45 shows a longitudinal section of the

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grate of a Lancashire boiler provided with the Green apparatus. The lower part of the bridge chamber, *c, c*, is simply a heating chamber for the air which passes through it; the upper part, *D, D*, is a mixing chamber, in which the hot air and smoke-laden gases from the fire grate mingle, and produce perfect combustion; *e¹* is a movable door to the air-heating chamber *c*, and is operated by the lever and handle *f*.

The claims of Patent 19,631 are as follows—

1. The herein described improvement connected with the combustion of fuel in furnaces, namely, supplying heated air and gases of combustion from the fire, into a chamber at the bridge, in which the air and gases mix, and then passing such gaseous mixture through perforations in the roof of the bridge, over which the main body of the gases of combustion pass; for the purposes set forth.

2. The herein described improvement connected with the combustion of fuel in furnaces, namely, supplying heated air, gases of combustion from the fire, and cold air in regulated quantities into a chamber at the bridge; wherein said airs and gases mix, and the mixed fluid issues in streams, upwards into the gases of combustion passing longitudinally from the bridge; for the purposes set forth.

3. In a furnace, the combination of a chamber *c* with a perforated bridge roof, and hollow fire bars, *h*, communicating between said chamber and the ashpit for supplying hot air to said chamber; substantially as set forth.

4. In a furnace, a hollow chamber *c* formed as the bridge, as described, the upper portion of which is in the form of a hollow bridge *d*, having a perforated roof *d¹*; as herein set forth.

5. In a furnace adapted for promoting complete combustion and preventing the formation of smoke, a hollow bridge *d*, having a perforated roof *d¹*, and a perforated or open front end or wall next the grate; as set forth.

6. In a furnace, the chamber *c*, the hollow bridge *d* with openings *d¹* in its roof, and openings *d²* in its front wall or end, hollow or air heating fire bars *h* communicating between the ashpit and said chamber, and an opening *e* and regulator *e¹*, communicating between the ashpit and said chamber; as set forth.

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No. 535 OF 1901

This Patent is granted to J. C. PARKER for "IMPROVEMENTS IN STEAM GENERATORS." The greater part of the Patent Specification relates to improvements and modifications of the tube design and setting, in ordinary water-tube boilers, but its essential feature from the smoke-consuming standpoint

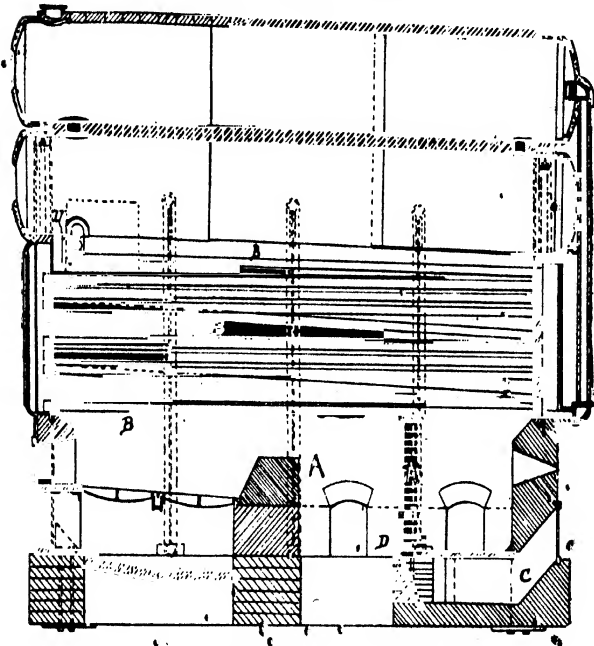


FIG. 46. THE PARKER WATER-TUBE BOILER SETTING.

is the provision of a secondary combustion chamber behind the grate, with a special supply of heated air. Fig. 46 is a sectional elevation of the Parker improved boiler setting; and in this *A* and *A* represent the secondary combustion chambers, in which

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the combustion of the furnace gases is completed *before* they come into contact with the first rows of tubes. The three baffle plates, *B, B* and *B* cause the gases to take a zig-zag course in ascending through the tubes of the boiler. The secondary air supply comes in at *C* and *D*.

Claim 13 of the Parker Patent relates to this feature of the boiler setting, and is worded as follows—

13. In a water tube generator, a furnace, with grate bars, a bridge wall at the rear of said grate bars, a chamber at the rear of said bridge-wall, vertical air ducts 44, of refractory material, perforated in the walls thereof, in said chamber, having vertical slots 88 between said ducts for the passage of flame and air therethrough, air passage *a*, and air door 45, substantially as specified.

No. 3,050 OF 1901

A Patent in the name of JOHN ALVES and THE
BRITISH FUEL ECONOMIZER AND SMOKE PREVENTER,

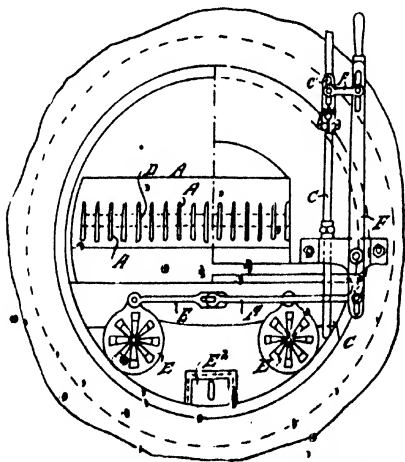


FIG. 47. THE ALVES BRIDGE AIR SUPPLY APPARATUS.

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LTD., for Improvements in Smoke Consuming Apparatus.

The essential feature of this apparatus is a bridge supply of air and steam, under the control of the fireman. The steam can be super-heated if desired, and the air supply can also be heated by passing

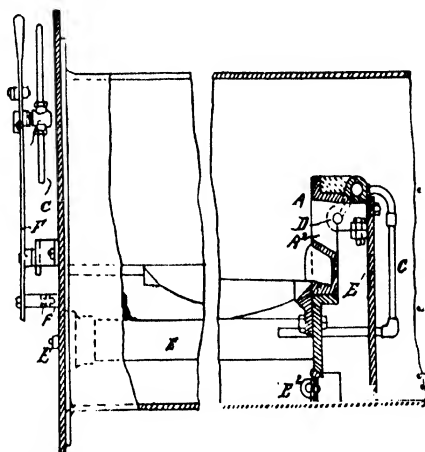


FIG. 48. THE ALVES BRIDGE AIR SUPPLY APPARATUS.

through channels in the bridge-wall. Fig. 47 shows a front elevation of a boiler furnace provided with this apparatus, and Fig. 48 is a longitudinal sectional elevation of the bridge-end of the same. *E c* is the air supply channel, which can be closed by the lever *F*; *a, a*, are the air admission slots in the bridge-wall; *D* is the steam pipe which supplies the injectors, and *E¹* is the chamber in which the air supply is heated before injection into the furnace gases.

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The claims of this Patent are as follows—

1. In smoke-consuming apparatus for steam-boiler and other furnaces wherein heated-air, under the influence of steam-jets, is supplied to the furnace, a bridge formed with alternate sets of passages, one set serving for the conduct and heating of the air prior to its meeting the steam-jets, and the other set serving for the conveyance of the heated-air to the furnace after the same has come under the direct influence of the said steam-jets, substantially as herein described.

2. In smoke-consuming apparatus for steam-boiler and other furnaces wherein heated-air, under the influence of steam-jets, is supplied to the furnace, a bridge provided with conduits or passages *a* open at each end to a chamber *E*¹ and serving to conduct and heat the air passing therethrough alternating with slots or passages *a*¹ for the conveyance of heated-air to the furnace under the influence of steam-jets, substantially as set forth.

3. In smoke-consuming apparatus for steam-boiler and other furnaces wherein steam-jets are employed to inject streams of air through slots or perforations formed in the bridge, simultaneously regulating the supply of steam, and air to the bridge, substantially as herein described.

4. In smoke-consuming apparatus for steam-boiler and other furnaces wherein, under the influence of steam-jets, heated-air is supplied to the furnace through a slotted or perforated fire-bridge, a steam superheater constructed and arranged sub-

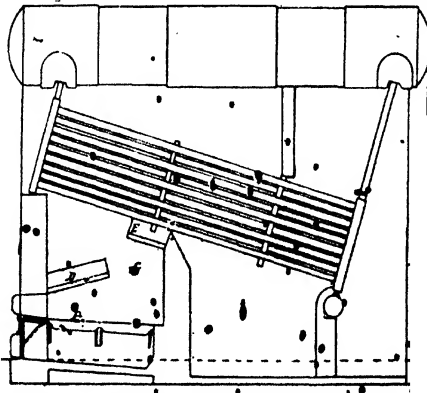


FIG. 49. THE MILLER WATER-TUBE BOILER SETTING

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stantially as herein described and whereby its removal for repair or renewal without disturbing the bridge is facilitated.

No. 2,893 OF 1901

This Patent is granted to H. W. MILLER for "IMPROVEMENTS IN FURNACES OF STEAM BOILERS"; especially of Water-tube Boilers. The essential

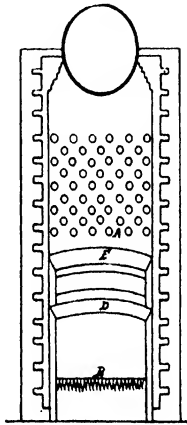


FIG. 50. THE MILLER WATER-TUBE BOILER SETTING.

feature of the Patent is the plan for forming a large combustion chamber or chambers lined with some non-conducting and refractory material, above the furnace grate, in which the hot gases and air can mix and produce complete combustion, before contact with the colder water-tubes of the boiler.

Figs. 49 and 50 show the Miller improved setting, as applied to an ordinary water-tube boiler, in longitudinal and cross-sectional elevation. The two fire-brick arches, *D* and *E*, form the lower and

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upper walls of this combustion chamber, and the tubes of the boiler are raised about two feet higher than in the usual method of setting, to allow for its construction. There is only one claim in the Miller Patent, and it is worded as follows—

In water-tube boilers the provision of a firebrick lined combustion chamber between the fire and the tubes, formed of two arches at different levels, and the provision of a second chamber in which the temperature of the gases is high enough for combustion to be completed, substantially as and for the purpose herein described.

The Miller Patent Water-tube boiler setting is in use at the Kensington and Notting Hill Electricity Supply Works, at Glasgow Electricity Works, and also at Messrs. Crompton's works at Chelmsford, with satisfactory results.

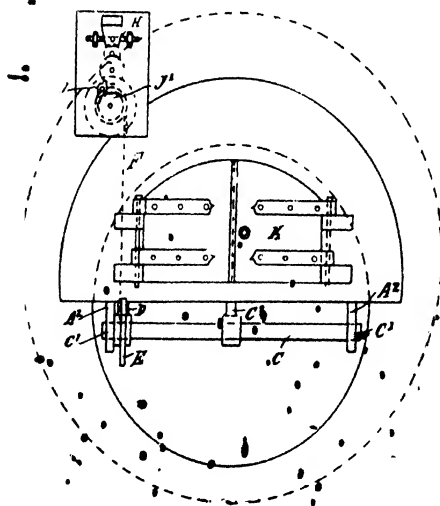


FIG. 51. THE CLARK AUTOMATIC AIR REGULATION MECHANISM.

APPENDIX I

No. 12,938 OF 1901

A Patent granted to A. M. CLARK (for C. H. Gould of Melbourne) for an IMPROVED SMOKE PREVENTER AND FUEL ECONOMIZER. The essential feature of this patent is the provision of AUTOMATIC APPARATUS for controlling the air supply to the furnace. Clock-

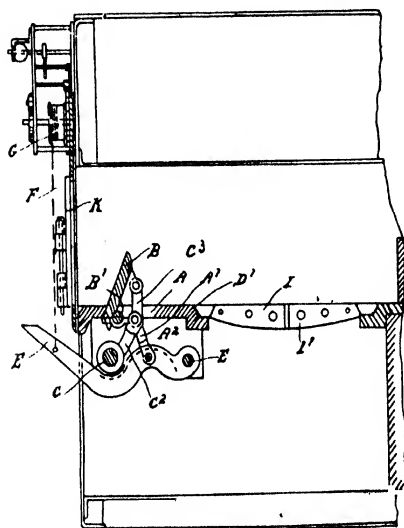


FIG. 52. THE CLARK AUTOMATIC AIR REGULATION MECHANISM.

work mechanism is used for opening and closing the slides, or valves which regulate the air supply, this being delivered through the dead-plate of the furnace grates, just inside the furnace doors. The mechanism is so adjusted that the slides are fully open directly after charging fresh fuel, and they gradually close as the volatile gases in this fuel are distilled off and

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burnt. Figs. 51 and 52 show a plane elevation of a boiler front, and a sectional side view of the grate, fitted with the Clark Automatic Air-supply mechanism.

The following are the claims of this Patent—

1. An improved smoke preventer and fuel economizer for furnaces consisting of a hinged or pivoted door or valve as *B* fitting an opening as *A* in the dead plate, said door or valve being controlled by clock mechanism or a clock train in order to close the door or valve in a predetermined time substantially as described and shown.

2. An improved smoke preventer and fuel economizer for furnaces consisting of a dead plate as *A* having an opening as *A* in it, a pivoted door or valve as *B* adapted to fit such opening, jointed levers *C*² and *C*³, rock shaft *C* lever *E* and jointed levers *D* *D*¹ combined with a clock mechanism or clock train time regulating gear, substantially as described and shown.

3. In an improved apparatus of the type specified the combination of the clock mechanism with the regulating device or governor *H* *h* substantially as and for the purpose described.

4. The improved smoke preventer and fuel economizer for furnaces constructed, arranged and operated substantially as herein described and as illustrated in the drawings.

No. 14,597 OF 1901

This Patent is granted to HORNSBY, ROBERTS AND JAMES for "IMPROVEMENTS IN STEAM GENERATORS."

The essential feature of the Patent is the provision of a fire-clay backing to certain parts of the tube construction in water-tube boilers, in order to obtain a higher degree of temperature and better combustion of the volatile gases. Fig. 53 is a sectional elevation of a boiler provided with these additions, *D* being a fire-clay tile backing to the lowest row of tubes *c*, and *E* being a hanging row of tiles or bricks on that portion of the lowest row of tubes, which is

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just above the bridge-wall of the furnace. The claims of this patent are worded as follows—

1. In a steam generator of the kind described the combination of tiles and hanging fire bricks on the top portion of the tubes immediately over the furnace and bridge wall, substantially as, and for the purpose, described.

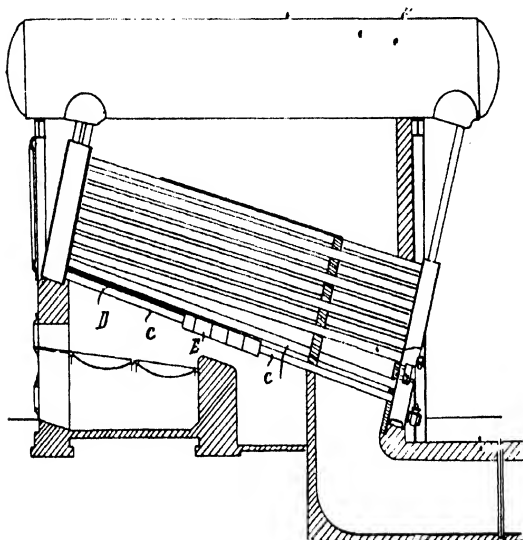


FIG. 53. THE HORNSBY IMPROVED SETTING FOR WATER-TUBE BOILERS.

2. In a steam generator of the kind described making the front header and the pocket which is riveted to the underside of the steam and water drum wide enough to take two or more rows of connecting nipples, substantially as described and illustrated.

3. The improved steam generator hereinbefore described and illustrated in the accompanying drawing.

No. 24,514 OF 1901

A Patent in the name of R. THOMSON, for "IMPROVEMENTS IN AND RELATING TO THE COMBUSTION

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OF FUEL IN FURNACES AND KILNS." The object of this invention is to obtain *perfect* combustion of the fuel and volatile gases, without the excess of air, that is usually employed, to attain this end. The essential feature of this Patent is the plan of feeding the fuel and the air for its combustion in a downward direction on to a hearth, or on to a bed of heated fuel; the products of combustion then escape

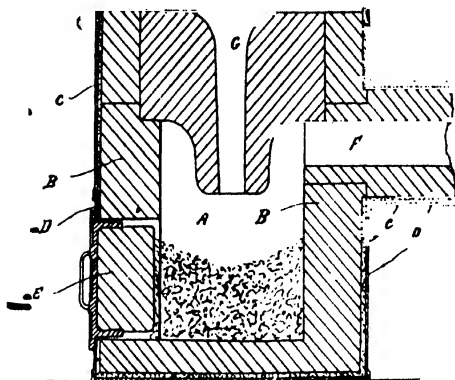


Fig. 54. THE THOMSON IMPROVED FURNACE CONSTRUCTION.

in an upward direction. The change of direction of the heated air, which is supplied under forced draught, and the method of feeding the fuel, is held to effect a much better mixing of the volatile gases and air, than is obtained by the usual system.

The improved method can be applied with equal success to solid and to liquid fuel, also to fuel in the powdered form. Figs. 54, 55 and 56 show the details of the furnace construction employed, for

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applying this method of firing to a Lancashire boiler.

An external furnace on wheels extends across the front of the boiler, and projections from this fit into the two boiler tubes. The openings *g g, g* into the furnace, are used for the supply of fuel and air to the hearth of the combustion chamber, *a*, and the

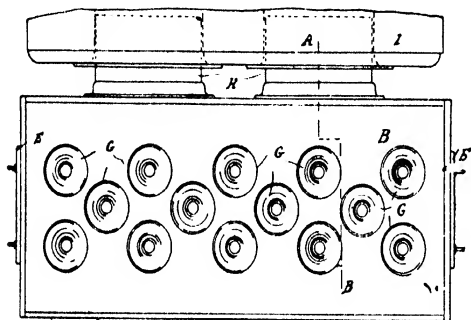


FIG. 55. THE THOMSON IMPROVED FURNACE CONSTRUCTION.

gases pass away from this by the openings *f* and *k*.

The ashes and clinker are removed by the end doors, *e, e*.

The wording of the claims of the Thomson Patent is as follows—

1. The method of effecting combustion of fuel, consisting in feeding the fuel in small regulated quantities into a furnace chamber, along with one or more downwardly directed streams of air on to a hearth of incandescent material, from which also all products of distillation and combustion are emitted upwardly whereby the fuel and all its combustible products are thoroughly commingled with sufficient air in a region of sufficiently high temperature, to effect complete combustion.

2. A furnace for the combustion of solid, liquid or pulverized

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fuel, comprising a furnace chamber having a hearth carrying incandescent fuel or other material, one or more suitable air inlets over the hearth through which fuel also is fed so that it is thoroughly brought into contact with the air supply during distillation or vaporization while surrounded by incandescent material, escape of waste gases taking place upwardly in a direction opposite to that of the inflowing air.

3. In a furnace as claimed in Claim 2, an air inlet orifice or

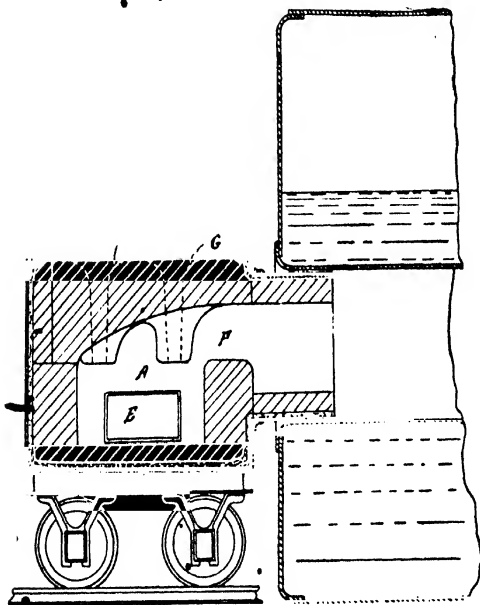


FIG. 56. THE THOMSON IMPROVED FURNACE CONSTRUCTION.

tube, bell-mouthed outwardly at its upper extremity, and of such length as will give the requisite direction to the stream of air flowing through it.

4. In a furnace as claimed in Claim 2, air inlets as claimed in Claim 3, together with outlets for the products of combustion so proportioned in relation to the air inlets as to produce the maximum induced draught, substantially as described.

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5. In the process of combustion claimed in Claim 1, delivering liquid fuel into the air inlet passages in such a way that vaporization takes place in the air stream.

6. In a furnace as claimed in Claim 2, spraying liquid fuel on to the sides of the air inlet orifice, or delivering it on to a rod within such orifice, whereby vaporization takes place from the hot lower walls of said orifice, or rod, and thorough commingling with air is also effected.

7. The improved furnaces hereinbefore described with reference to the accompanying drawings.

No. 7,373 OF 1902

This Patent is granted to J. WILSON and G. S. KEMP-WELCH, for "IMPROVEMENTS IN APPARATUS FOR PREVENTING SMOKE IN FURNACES." Its essential features are a hollow fire-bridge, of chequered

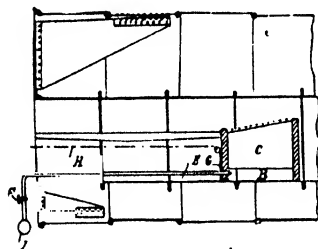


FIG. 57. THE WILSKEMP FUEL ECONOMIZER APPARATUS.

brickwork, named the "Regenerator," and a gas-producing apparatus for supplying gas for heating this hollow bridge at stated intervals, during the combustion process.

Fig. 57, is a sectional elevation of a Lancashire boiler fitted with the Wilson and Kemp-Welch apparatus, and Fig. 58 is a sectional plan of the same. The hollow bridge C is connected with the

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gas-producer by the main-pipe *d* and branches *e, e*. When no air is being drawn through *e*, the cocks *F, F* are opened, and the bridge chequer-work is raised to a high temperature, by the ignition of this gas in its interstices. When firing is going on, the gas supply is turned off, the air inlet *g*, is opened by means of the lever *H*, and heated air is supplied above the bridge, for combustion of the smoke and

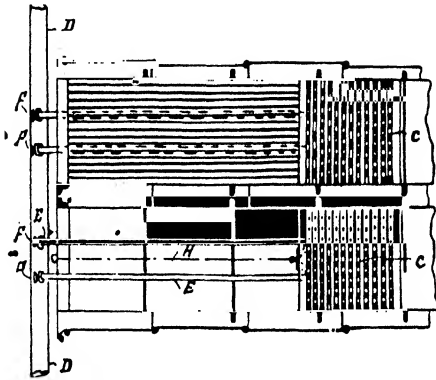


FIG. 58. THE WILSKEMP ECONOMIZER APPARATUS.

volatile gases passing off from the furnace grate.

The claims of this Patent are as follows—

1. The combination with a furnace of a regenerator supplying air at the back of the fire substantially as described.
2. Apparatus for preventing smoke in furnaces substantially as described and illustrated in the drawings.

No. 10,941 OF 1906 AND No. 7,034 OF 1909.

The E. C. Mills furnace is arranged to give "true principle" combustion and **SMOKELESSNESS** by means of—

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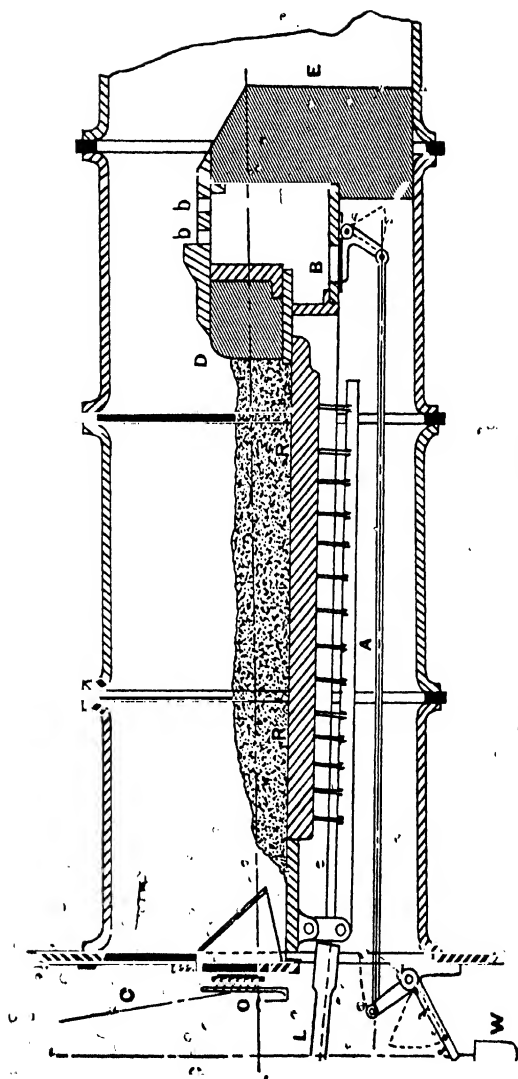


FIG. 50. THE E. C. MILLS APPARATUS.

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O. "Louvre" air openings in the door shown open to allow extra air to enter for the combustion of the hydrocarbon gases given off immediately after feeding fresh fuel.

B. An air valve shown closed to permit temporary passage of extra air from ashpit to openings *b, b*, for further secondary combustion of gases at the back of the grate.

c, c. Steel cords operating "*O*" and "*B*," closing them automatically and gradually as soon as the demand for extra air ceases.

R. Hand rocked firebars, operated by socket lever *L*, and rod *A*.

D. Ordinary firebrick bridge.

E. Firebrick back bridge wall. The steel cords must of course be operated by some moving shaft or other device.

PRE-HEATED AIR

In supplying heated air it has often been stated that effects cannot be obtained equal to those with cold air. This, no doubt, is, in a sense, true. The heating of air expands it, and the spaces through a grate being somewhat limited, it is not unreasonable to expect some difficulty in passing through such additional volume. Success with hot air is rationally to be expected, but perhaps only as a rule, when the draught is assisted as by a fan, which compels a sufficient volume of air to enter the furnace through the grate. It cannot of course be for a

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moment argued that air should not be used hot. Its only trouble has been the difficulty in using enough of it.

Some idea can be gained as to the economy of heating air. Let it be supposed that the air supply is all heated 400°F . above atmospheric temperature and that the furnace temperature is ordinarily $2,500^{\circ}\text{F}$. The heating of the air will raise the furnace temperature to $2,900^{\circ}\text{F}$. nearly. If the air has derived its heat from a waste source as from the chimney the economy will be as 29 to 25, or about 16 per cent. This of course presumes a somewhat high temperature of the waste gases as well as an excessive weight of air per pound of fuel, or the furnace temperature would be higher. As a second example assume better conditions or a furnace temperature of $3,000^{\circ}\text{F}$. and air heated 300°F . then the furnace temperature will become $3,300^{\circ}\text{F}$. and the economy is 10 per cent. In addition to this calculated economy there would be the general better combustion and the reduction of the smoke due to better temperature. The efficiency of heat transmission to the water through the boiler plates would be improved by the greater head of temperature. But there would be less chimney draught owing to the abstraction of so much heat by the air supply. The heating of air may in general be regarded as appertaining to that class of improvements to be looked for when a fan induced draught is employed in place of a chimney draught. A fan works better with colder gases and the air heater would naturally and properly stand between the

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boiler and the fan so as to give this the best position to act on coldest possible gas. But heated air under the conditions of a fan draught may be found advantageous even if the air be heated in the boiler flues, though usually there would not be room for an efficient apparatus.

In blast furnace work the blast is heated by being passed alternately through two firebrick chambers of brick chequer work through which burning waste gas is the alternating current. Possibly some such system would be a good air heating system for boiler work, but it may be said that all such systems imply resistance and demand assistance by way of fans or jets of steam. As a rule a draught aided by a steam jet is expensive and steam as an aid to draught has made its successes where by means of the better draught inferior fuels are used. By inferior fuels are meant fuels which, whether inferior or not in calorific value per pound, are of less cost per thousand heat units of value. Most "inferior" fuels are so called, rather because they are of small size and difficult to burn at high rates per unit of grate area than because they are essentially of poor quality.

As a rule the benefits of heated air are more easily secured in furnaces for other purposes than steam raising. Thus in a crucible furnace the waste gases must flow away hotter than the intensely heated crucible, and where so much high temperature heat is going to waste it is an easy matter to recover much of it and supply the furnace with highly heated air. Such furnaces, known as regenerative, are then

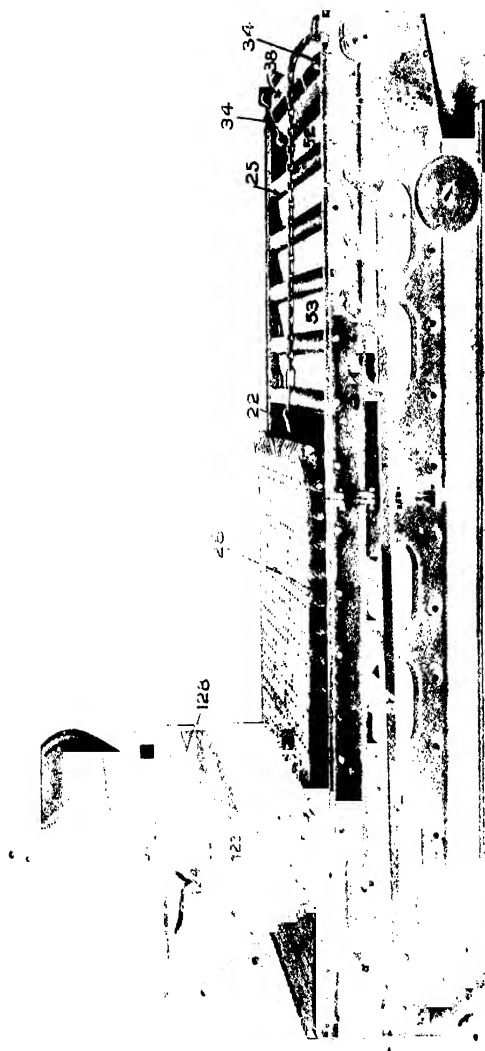


FIG. 60. CHAIN GRATE FOR WATER-TUBE BOILER SHOWING AIR CUT-OFF PLATES UNDER GRATE.

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easily raised $1,000^{\circ}$ or $1,500^{\circ}$ degrees above the temperatures they would acquire with unheated air.

THE BABCOCK CHAIN GRATE

This travelling chain grate as shown in Figs. 60 and 61, is built up of closely connected short links of cast iron. The fresh coal is fed in from a hopper 105 and spread evenly on the grate by an adjustable plate. As the grate travels forward and the fuel burns away the access of air becomes too easy. To remedy this a number of swivelling plates under the grate are provided and can be adjusted to any suitable opening by means of levers 55 and rod 57 actuated from the front of the boiler. The whole is carried on wheels 23, 24 running on rails so that the complete furnace can be drawn from under the boiler. In the line drawing the shut-off air plates are shown in solid black. At the back end

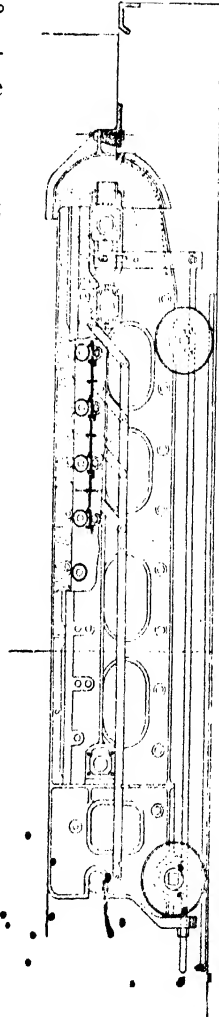


FIG. 61. CHAIN GRATE STOKER SHOWING AIR CUT-OFF PLATES IN BLACK.

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of the furnace the grate runs round a half cylinder casting which serves to prevent excess of air passing at this point also. The ash is dumped over the plate at the rear of the grate into a trapped ash-pit hopper whence it is dropped into an ash traveller placed in the basement.

AN INCANDESCENT CORE FOR BOILER FURNACES

An example of the application of refractory material to the conservation of temperature during combustion of the hydrocarbons is that of the Incandescent Heat Co. who build a horseshoe shaped core in the tubes of a Lancashire boiler. Through this central tunnel pass the gases from the furnace. At the end of the boiler they return along one side of the core between it and the furnace tube. Arrived near the bridge end again they return again on the other side of the core and pass to the bottom flue. There is thus no covering up of any part of the boiler surface. The gases are made to move rapidly and they are not allowed to cool until they have traversed the length of the core in which they have time thoroughly to mix so as to make use of a minimum volume of air and complete their combustion before becoming chilled. It must be said that this design appears to combine the requisites of a refractory surface beyond the bridge with a preservation of the full heating surface of the boiler in a very ingenious manner and that the

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increased velocity of flow of the gases is in itself sound in principle so far as it does not add unduly to the resistance of the flues. Even if this proved to be the case the apparatus would work with fan draught. Indeed this apparatus is a clever attempt at combining the essentials of perfect combustion within a boiler of regular commercial type without making any structural change in the boiler itself. The cores can be removed for boiler inspection purposes.

INTRODUCTION OF AIR

There are innumerable appliances for the introduction of both hot and cold air for the purposes of smoke prevention. Some of these introduce air at the bridge, others through the door or through the dead plate. The air is sometimes heated. In all cases it ought to be admitted in a finely divided state by the aid of perforated inlet plates or grates. The heating is sometimes performed by passing the air through hollow grate bars which open into a hollow bridge whence the air, now hot, is discharged into the mass of gas flowing from the furnace. Steam jets are sometimes employed to force the air through these long hollow bars. In most cases there is no automatic regulation of the air and the danger of hand regulation is, that, if not attended to, an excess of air enters the furnace after the hydrocarbon gases have ceased to be evolved and the whole of the boiler is needlessly cooled. Broad-

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bent's clockwork device has been described on page 65. In the regulation device of the Cowper Coles Patent furnace the air driven in by a fan or other device passed through a water box so arranged that by means of an escape hole the water rose in the box and gradually trapped off the air. When the furnace door is opened the water level is lowered and gradually recovers itself by means of this leak.

It is important that the air should thus be automatically shut off. The Cowper Coles patent also includes masses of special refractory firebrick in the flues to act as temperature equalizers and promote the ignition of the green gases.

THE UNDERFEED STOKER, of South Place, London, is shown in Figs. 62 and 63. In this machine, coal is fed up a long central trough, by means of a tapering helix, and it becomes partly coked before it rises from the top. The sides of the trough sometimes have a lateral movement, which slightly crushes the rising coking fuel.

As the fuel rises, it falls over on each side, upon the two inclined grates, of longitudinal hollow flat plate bars, under and through which air is blown. This air passes out parallel with the bar faces, and thus mixes better with the fuel, and does not so readily escape upwards, untouched. The plates have a rocking movement, which helps the fuel downwards to the long side troughs, whence it can be raked when all is burned to ash. These underfeed stokers generally may be said to resemble

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a pair of step grates set back to back, with the fuel supply at the common ridge between them. They are then, to some extent, a compound of a coking system and a gravity or inclined grate system, and the air supply is directed so as not to escape too readily and create bar patches in the fire. These underfeed laterally sloped grates, appear to afford something of the gravity effect, with a grate longitudinally horizontal, and they can be employed

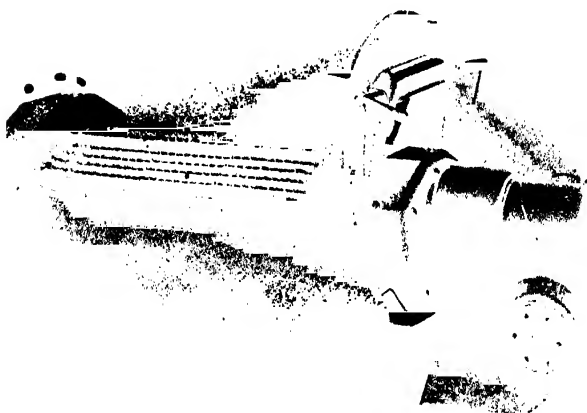


FIG. 62. THE UNDERFEED STOKER.

where the highly-inclined step grates cannot be accommodated, as in the furnaces of Cornish or Lancashire boilers. They are used always with assisted draught. Under-firing cannot be said to have proved a success until, by means of gravity, the fuel was made to travel over the grate surface, and this was only secured by inclining the grate surface trans-

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versely as shown. By this lateral sloping alone could a really inclined grate be secured in an internally fired boiler. In Fig. 63 the fuel is marked *G*; *D* is the trough in which works the helix which feeds forward the coal; *F*, *F*¹ are the first air inlets supplying air to the fuel at *E*, just above the mov-

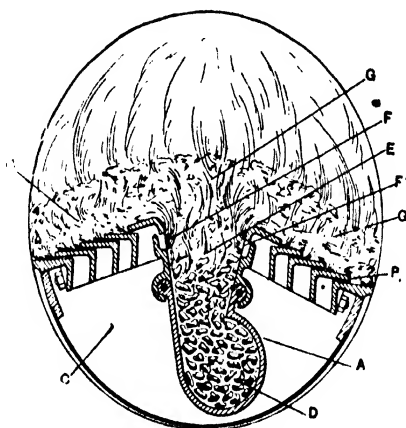


FIG. 63. THE UNDERFEED STOKER.

ing sides of the hopper, which crush the fuel when it begins to coke as it approaches the heat. Air enters through the slots in the bar edges as at *G*, and air is forced by a fan to the undergrate space *A*, *C*.

The E.S.E. Stoker, of Blackburn, Lancashire (Figs. 64, 65), consists of a sprinkling gear which acts first to sprinkle the coal upon the right side of the grate from dead-plate to bridge. Then the

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apparatus pauses, and the left side of it comes into operation and feeds fuel on the other half of the fire, thus mechanically imitating side firing, and

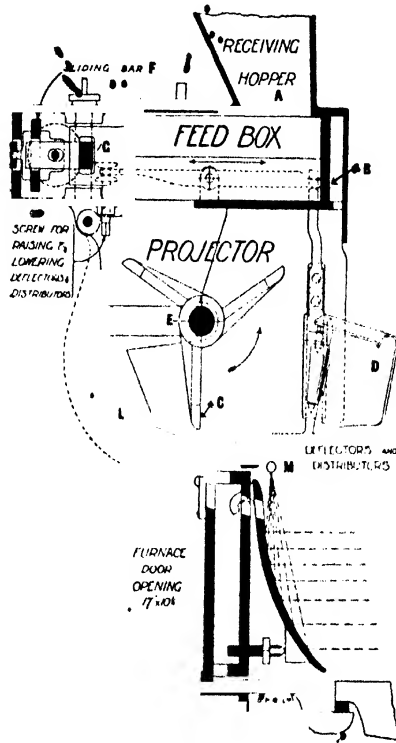
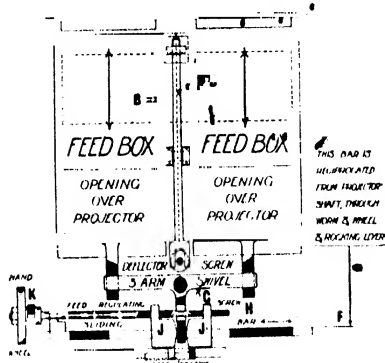


FIG. 64.

providing always that one side of the furnace shall be bright while the other is giving off gases freely. The object aimed at is to keep a fairly constant gas output to be consumed by aid of the surplus air

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admitted at the door, and of the temperature provided by the clear, red half of the fire.



THE "E.S.E." PATENT MECHANICAL STOKER

REFERENCE.

- A - Coal receiving hopper.
- B - Sliding feed boxes.
- C - Three arm projector.
- D - Deflectors and distributors.
- E - Projector shaft, 300 revs. per minute.
- F - Sliding bar with blocks J.
- G - Three arm swivel, working boxes B.
- H - Feed regulating wheel on bar F.
- J - Feed regulating blocks on bar F.
- K - Feed regulating hand wheel.
- L - Projector casing relief door.
- M - Jet pipe, for clearing dead plate.

Fig. 65.

B. GERMAN PATENTS

No. 79,015 OF MAY, 1894

This Patent is in the name of G. W. KRAFT, of Dresden, and relates to an inclined grate method of firing. Fig. 66 is a sectional elevation of the same. At the upper end of the inclined grate A, there is fixed the charging hopper B, which is movable and slides vertically, so that a larger or smaller portion

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of the grate may be covered by its lower end. The angle of the grate and hopper is selected so as to give a regular feed of the coal to the lower part of the grate; and this feed of course increases as the charging hopper is withdrawn, and a larger por-

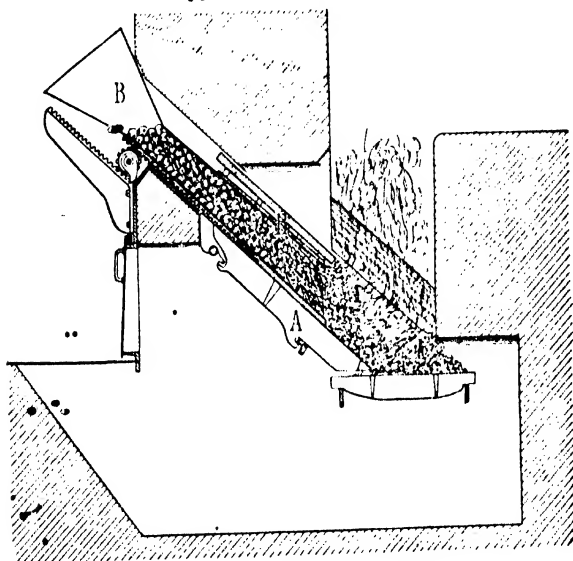


FIG. 66. KRAFT'S INCLINED GRATE FURNACE CONSTRUCTION.

tion of the grate surface is rendered available for the combustion process. Any mechanical device may be utilized for moving the charging-hopper, and causing it to rise or descend in the grate.

The Patent claim is as follows,—

A grate for burning poor fuel, distinguished by a movable

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charging hopper, that can be withdrawn from the furnace, and which may be utilized to increase or lessen the size of the grate, and therefore of the fire.

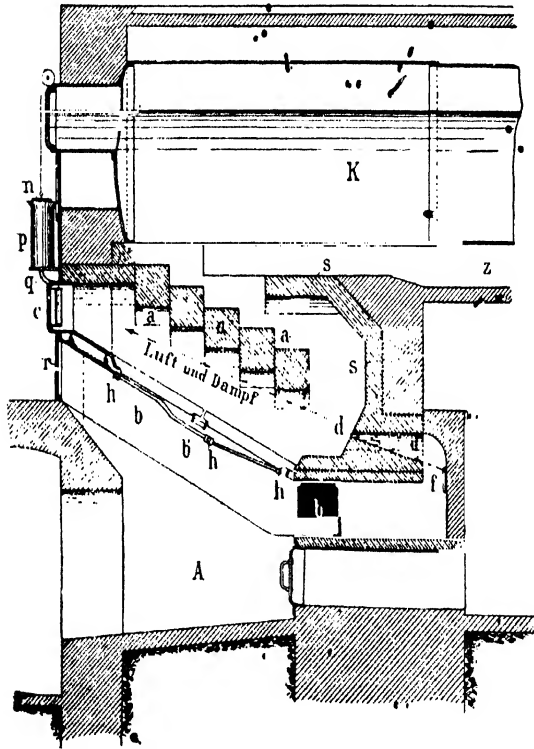


FIG. 67. KRIPPE'S GATE AND FURNACE CONSTRUCTION.

No. 91,332 OF 1896

A Patent granted to A. KRIPPEL, of Vienna, and
illustrated by Figs. 67 and 68.

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The claim of this Patent is as follows—

A furnace and smoke-consuming apparatus, distinguished by an automatic air supply device actuated by the furnace door.

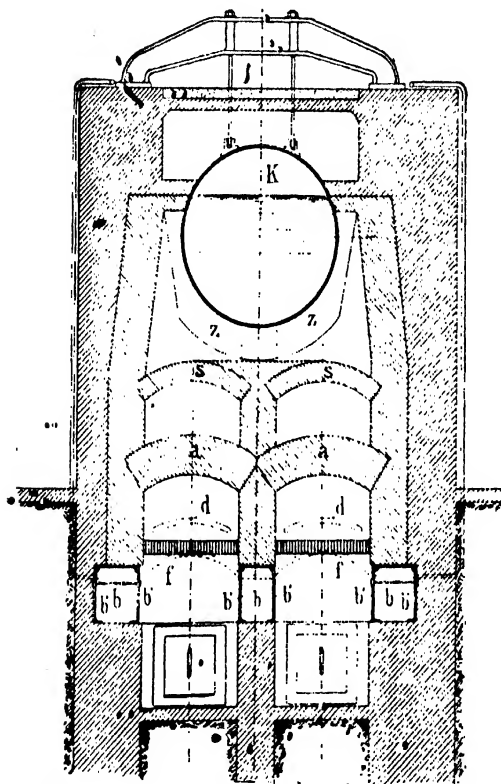


FIG. 68. KRIPPEL'S GRATE AND FURNACE CONSTRUCTION.

On opening the furnace door *C*, the sliding damper is raised, and air is admitted either to the bridge, or to the ash-pit, of the furnace, by channels *b b b*, in which it is heated by contact with iron walls. This heated air then passes through the fuel on the

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grate, or through the openings d d in the bridge, and promotes the combustion process.

In the latter case, it passes as a current of heated air above the grate, in a contrary direction to that of the half-burnt gases, and the arched wall above the grate is built in step-fashion, to promote the better mixture and combustion of the mixed gases. Fig. 66 is a side, and Fig. 67 a front sectional elevation of this type of furnace construction, applied to a cylindrical boiler.

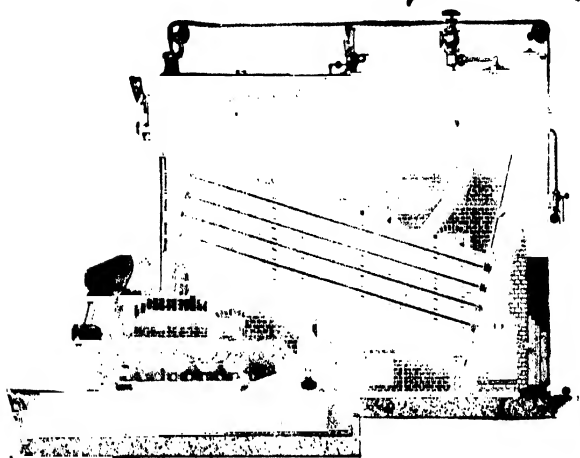


FIG. 69. WATER-TUBE BOILER SHOWING CHAIN GRATE AND OVERARCH.
(See p. 194.)

No. 96,185 OF 1897

The Patentee of this improved furnace is C. H. C. Bock, of Hamburg, and the Patent relates to an automatic device for feeding the fuel slowly and regularly on to the fire. The apparatus is illustrated in Figs. 70 and 71, which represent a sectional elevation and sectional plan of the furnace respectively. A box (u) projecting from the front of

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the furnace has a hinged false bottom *b*, which is kept in position by the weighted lever *b*². The weight *c* keeps the bottom *b* from falling downwards, and causes it, and the fuel upon it, to be slowly pressed upwards, round the curved outer wall of *a*,

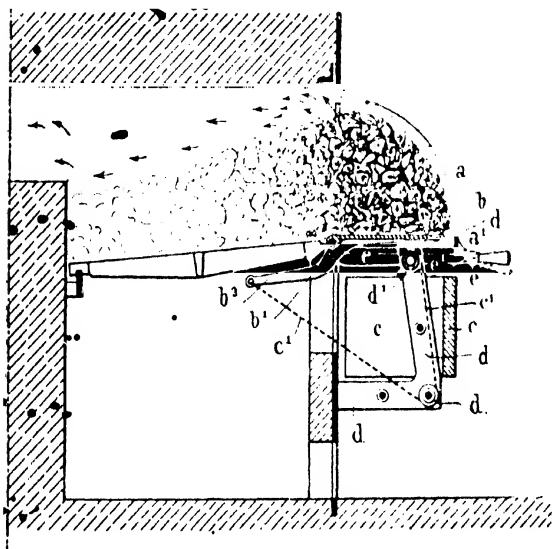


FIG. 70. THE BOCK GRATE AND FURNACE.

into the furnace. When charging the hopper with fuel, the action of this weighted lever is checked by a suitable mechanical device.

The claim of this Patent covers—

Grates for furnaces of all kinds, provided with a projecting fuel box, characterized by a movable bottom, and a mechanical

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device for carrying the fuel resting on this false bottom gradually into the zone of combustion.

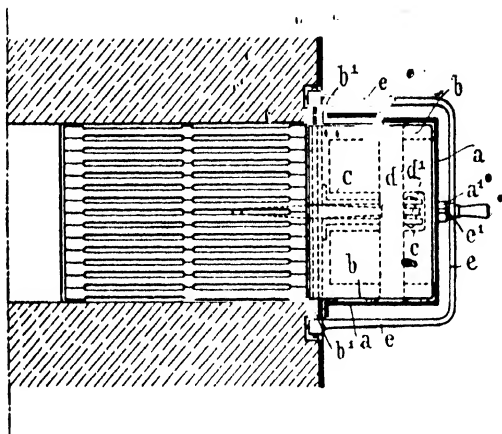


FIG. 71. THE LOCK GRATE AND FURNACE.

No. 112,156 OF 1899

This Patent was granted to W. DÜRR, of Munich, and relates to improvements in the provision of a secondary air supply, for boiler furnaces with inclined grates.

Fig. 72 is a sectional elevation of this improved furnace construction, and requires no detailed explanation.

The Patent claim covers—

The use of a hollow arch over the inclined grate of the furnace, for heating the secondary air supply, the passage of the air through the channels in this hollow arch being in an opposite direction to that of the heated gases outside it.

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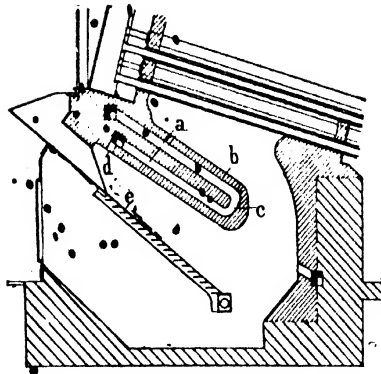


FIG. 72. THE DÖRR FURNACE CONSTRUCTION.

No. 114,909 OF 1899

A Patent granted to A. PIONTEK, of Braunschweig, for an improved form of external revolving hearth furnace for boiler firing. Fig. 73 is a sectional elevation of this furnace; and in this *F* represents

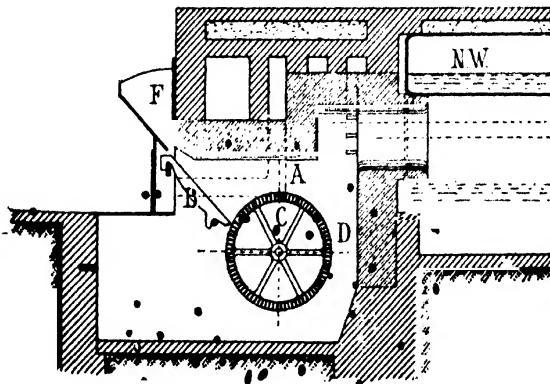


FIG. 73. PIONTEK'S REVOLVING HEARTH GRATE.

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the fuel charging hopper, *B* an inclined grate, *C* the revolving hearth, *A* the combustion chamber, and *D* a space which becomes filled up with half-consumed carbonized fuel and ashes. The movement of the revolving hearth *C*, of course carries the fuel from *B* towards *D*, and also assists in the movements of the carbonized fuel and ashes towards the bottom and front of the ash-hole ; and all these features of the design are covered by the wording of the Patent claim.

No. 116,063 OF 1900

This Patent was granted to H. BÖTTGER, of Dresden, and relates to an improved method of feeding coal or slack on to the grate of a boiler or other fur-

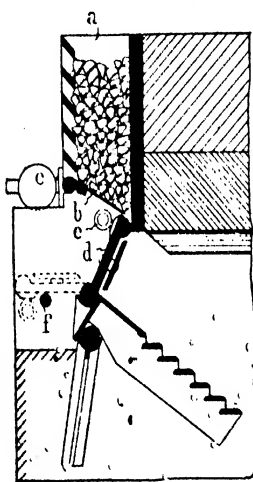


FIG. 74.
THE BÖTTGER AUTOMATIC FEED
GRATE.

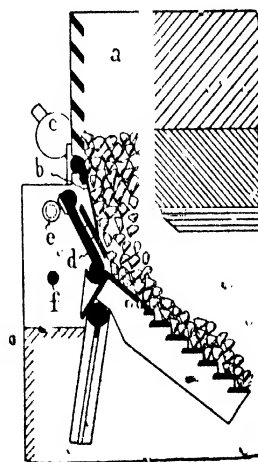


FIG. 75.
THE BÖTTGER AUTOMATIC FEED
GRATE.

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nace, without admission of air. Figs. 74 and 75 show the arrangements of parts for effecting this object.

d is a heavy lugged door which when closed, as in Fig. 74, acts as support for the hinged door *b*, supporting the charge of fuel in the hopper *a*. *d* can either be opened by hand or by automatic mechanism, and then takes the position shown in Fig. 75. The swing bottom *b* of the hopper *a* then falls back, and the charge of fuel falls on to the inclined step-grate. A balance weight *c*, attached to a lever acting on *b*, causes the two doors *b* and *d* to close, before all the fuel has dropped out of *a* on to the grate. The Patent claim covers all these details of construction.

No. 123,300 OF 1901

This Patent relates to a system of under-feed firing; and was granted to K. F. SCHUMANN, of Hosterwitz. Fig. 76 is a sectional elevation of this type of furnace. The charge of fresh fuel is placed in the charging chamber *c*, where it is subjected to a preliminary heating. When a fresh charge of fuel is required on the grate of the furnace, the hollow slide box *d* is pushed back by means of the lever, until it occupies the position indicated by *f* *g*¹. The charge of fuel in *c* then falls in front of *d*, and on returning this to its original position, the fuel is brought on to the grate *a*, underneath and behind the hot mass of carbonized fuel and ash already there.

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The gases liberated from the fresh fuel are therefore compelled to pass through the glowing body of fuel above them, in order to reach the combustion chamber of the furnace, and a more perfect combustion is claimed for this method of combustion and charging.

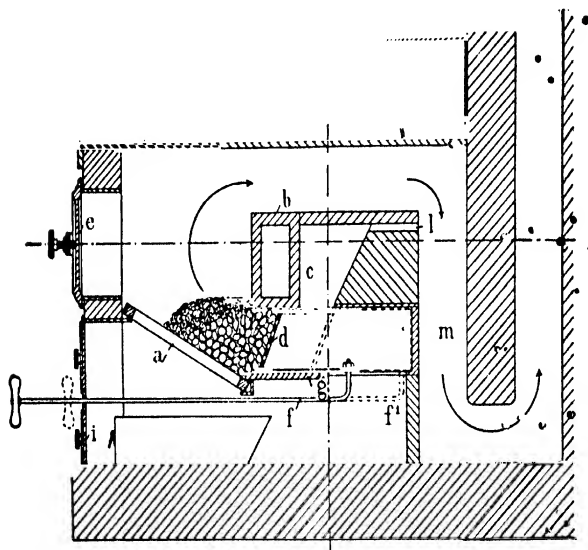


FIG. 76. THE SCHUMANN UNDER-FEED GRATE.

The Patent claim covers these details of construction and the results obtained.

AMERICAN PATENTS.

The smoke devices of America differ somewhat from those of this country, owing to the difference of boiler practice and the difference of fuel.

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Those selected for description will include modifications of the old Jukes chain grate, furnaces of the under-fired type, and the step grate.

THE COXE STOKER (Fig. 77) for hard or Pennsylvania anthracite, is of the chain-grate variety.

It consists of a chain, carrying a series of transverse flat-topped bars, on to which the fuel is fed from a hopper. The air supply is provided by a fan, which

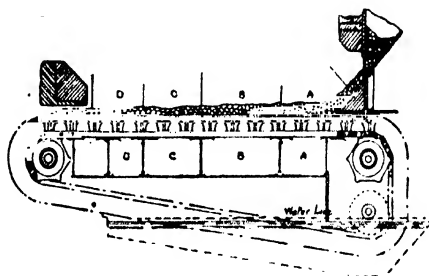


FIG. 77. THE COXE CHAIN GRATE STOKER.

delivers air into a sheet-iron box, under the chain. This box is divided by partitions in such a way, that whereas the division *B* secures the full supply, there is a moderate pressure in *A*, and diminished pressures in *C*, *D*, etc., to the end of the grate, the air supply being thus regulated to the thickness of the fire. The final box only passes air to cool the ash, and to burn the carbonic oxide, from the thicker parts of the fire. With a brick arch over the fire, to compel all the gases, to travel the full length of the grate before escaping to the boiler, it was found by Mr. Coxé that an evaporation from and at 212°F. of 10.14

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to 11·2 pounds, per pound of combustible was obtained. This stoker merits careful attention. The air regulation is what reason demands it should be, and there appears to be no cause why it should not suit bituminous fuel, and thus render the chain grate one of the foremost of apparatus. As already pointed out, the usual chain-grate apparatus is extremely faulty, owing to want of the air regulation plates, which are essential to a horizontal chain grate.

The extended use of under-fired shell boilers in America, has favoured the stepped grate type of furnace. One of these, mechanically operated, is the RONEY STOKER.

A slider in the bottom of the coal hopper, pushes the coal upon the grate, which has an angle of 37° from the horizontal. The grate bars are of the flat step variety, and rock from a horizontal position, to one inclined downwards. The rocking of the bar causes the fuel to gravitate downwards, filling up weak places in the fire, and gradually transferring the ash to a dumping plate at the foot of the inclined grate. The bar movement also serves to keep an open fire. A brick coking arch covers the upper end. It is important to note that the gravitation effect is only possible with inclined grates, and this is one great advantage of externally-fired boilers not possessed by any of the internally-fired variety. Where a fire can be caused to pack itself, and close up bare spots automatically, a better economy is possible than can easily be secured in any horizontal grate (see pp. 70, 71).

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THE ACME STOKER, Fig. 78, is another of the inclined grate variety, with an angle of 32° . Coal is fed over the small upper coking grates, under a brick arch. The fire-bars of the inclined grate are arranged so that alternate bars rise above the general level, move downwards, and return below level, so helping the fire to travel gradually towards the dumping grate at the foot. The whole grate

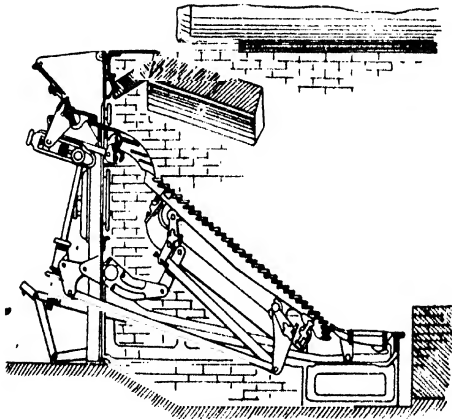


FIG. 78. THE ACME STOKER.

can be lowered in front to a flatter position, so that hand firing can be carried on through the door, which is below the grate when mechanical firing is in progress. The grate when fully charged and ignited, can then be raised to the full angle and mechanically operated as usual.

THE WILKINSON STOKER (Fig. 79) has a grate with a flat angle of 25° , and it consists of hollow

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bars through which air flows to the fuel. The air may be drawn in by a steam jet in each bar. Movement of the bars alternately to and fro, feeds forward the fuel. Value is placed on the use of steam, and in the illustration the idea of the makers of this furnace is set forth, showing that the incandescent fuel on the grate is supposed to be utilized to split

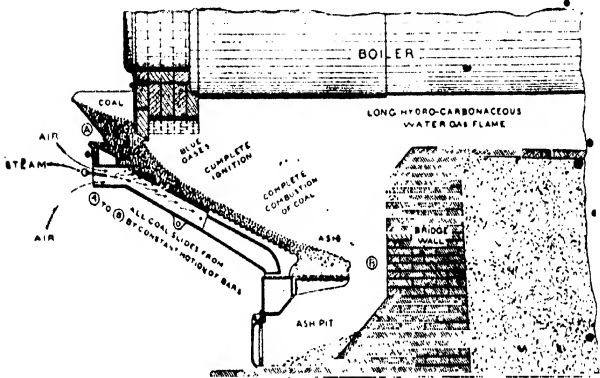


FIG. 79. THE WILKINSON STOKER.

up the steam into its elements, and thus to transfer the combustion to a long locus of flame beneath the boiler. The firebrick arch of this illustration could probably be extended with advantage. The grate, of course tends to give an even fire, and the final ash is dropped below, as shown. The Wilkinson Stoker is claimed to burn anthracite or bituminous coal. It is important that anthracite should not be allowed to burn into bare patches on the grate, and it is therefore necessary that the fire should

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have a self-closing action, without too much disturbance taking place. American hard anthracites should be disturbed as little as possible during combustion, being in this respect like the dry bituminous, or "self-stoking," coals of this country.

D. AUSTRALIAN PATENTS

THE COTTON FURNACE.—The Cotton Patent Furnace, an Australian invention, consists of a deep brick rectangular furnace with a solid bottom. Air is blown into it by a fan or by steam jets at a height of several inches above the bottom. In this manner any mineral matter in the fuel is run more or less in liquid form past the air entrances and the clinker and ashes are easily removed through a doorway in the furnace below the horizon of air entry. The invention thus aims at preventing any choking of the air admission to the fuel, and thus maintains a constant furnace régime so long as the ash and clinker are not allowed to accumulate above the proper level. Very inferior fuel can be burned, for any amount of dirt can be removed from the furnace which cannot be choked. No skilled firing is needed, the furnace is simply kept full of fuel. Air for burning the gases must be admitted above the fuel bed and the ash and clinker is raked out by a bottom door, thus allowing the fuel to descend to the level of the air entry and leaving space above which is filled with fresh fuel. The amount of dirt in the coal is thus almost limited only by the ability to rake out the ash, whereas with a

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grate it is limited at a much earlier point by the difficulty of keeping the grate free and open. This class of furnace may be said to be a half way measure between the solid fuel grate and the gas producer furnace.

Appendix II

TABLES.

Fuel Analyses, Losses and Costs

TABLE I
APPROXIMATE ANALYSES, CALORIFIC VALUES (CALCULATED AND OBSERVED), PRICES, AND COMPARATIVE COSTS OF VARIOUS ENGLISH AND WELSH COALS.
From Liverpool Engineering Society Paper, by J. B. C. Kewland, on "Fuel Economy," November 18, 1903.

General Description of Coal	Particular Description of Coal	1	2	3	4	5	6	7	8	9	10
		Per cent. Moisture	Per cent. Ash	Per cent. Coke	Per cent. Volatile Matter	Per cent. Fixed Carbon	Calorific Value (Calculated)	Calorific Value (Observed)	Calorific Value (Calculated)	Price per Ton at Bunkers	Calorific Value per Penny of Coal
Hard South Wales Coals	Eaglebush	1.05	14.25	86.70	13.30	72.45	7503	7503	—	17 9	35.2
	Dyce	1.35	10.75	76.40	13.60	75.65	7505	7505	—	18 2	35.7
	Standard Merthyr (1)	1.21	8.5	34.50	15.50	75.05	7642	7642	70.50	21 0	31.5
	Standard Merthyr (2)	1.27	2.45	82.40	14.10	77.50	7641	7641	70.50	21 0	31.5
	Cwmmer Main (1)	1.46	10.00	87.50	12.50	77.50	7635	7635	78.55	17 3	38.3
	Cwmmer Main (2)	1.45	5.55	87.60	12.40	78.00	7635	7635	82.50	17 3	40.0
	Dynevor Duffryn (1)	1.25	8.15	84.10	15.00	76.00	7687	7687	80.58	19 1	34.8
	Dynevor Duffryn (2)	1.20	6.75	87.40	12.60	77.65	7702	7702	78.75	19 1	33.0
	Pontardawe Smokeless (1)	2.66	8.40	87.60	12.40	79.50	7875	7875	79.05	17 3	36.3
	Pontardawe Smokeless (2)	4.48	15.25	88.20	11.80	74.05	7532	7532	73.08	17 3	36.9
Soft Bituminous Coals	Pontardawe	3.65	13.95	87.40	12.60	74.35	7532	7532	75.11	18 6	39.0
	Ocean Small Steam	3.15	13.05	87.00	13.00	73.00	7560	7560	75.11	18 6	41.5
	Loughor & Newydd	2.20	17.05	76.00	14.00	68.05	7330	7330	—	9 0	64.5
	Werfa	1.54	14.05	69.00	10.60	75.05	7331	7331	—	11 11	51.2
	Cannock Seam	10.62	23.05	70.15	20.85	47.10	6382	6382	—	6 9	78.7
	Kingswinford Slack	12.45	12.45	72.10	27.60	50.05	7207	7207	—	8 6	71.5
	North Hutton (1)	2.51	13.20	100.00	31.00	55.20	7506	7506	—	11 10 1	53.2
	Madeley Washed Slack	3.20	0.20	6.70	33.30	60.30	8041	8041	80.41	10 6	76.3
	Stoptord Slack	2.83	9.45	66.10	33.60	50.65	7500	7500	—	7 8	85.2
	Bowley Washed Slack	2.70	5.25	67.40	32.60	61.55	7505	7505	—	10 6	69.3
Soft Bituminous Coals	North Hutton (2)	2.64	11.40	66.70	30.30	58.30	7658	7658	76.58	11 10 1	54.0
	Wigan (1)	4.94	16.85	66.10	30.10	53.70	7245	7245	72.45	8 4	72.4
	Wigan and Skelmersdale (1)	6.76	16.50	71.20	28.80	53.70	7337	7337	73.37	8 4	73.8
	Wigan (2)	3.50	14.20	70.10	26.60	55.40	7509	7509	75.09	8 4	75.9
	Wigan and Skelmersdale (2)	3.70	14.20	69.60	30.40	55.40	7509	7509	75.09	8 4	75.9
	Wigan Bright Peas	10.44	6.50	63.50	30.50	57.00	7891	7891	78.91	7 9	85.3
	Shirley Peas	7.72	7.75	56.00	34.00	58.25	7764	7764	77.64	7 9	83.0
	Manhay Rough Slack	7.80	3.05	64.70	33.30	61.05	8314	8314	83.14	8 8	70.9
	Manhay Peas	7.44	10.75	66.40	33.60	55.65	7676	7676	76.76	7 5	80.2

8.—(1) The results in columns 3, 4, 5, 6 and 7 are all based on the sample dried at 111°C.
 (2) The results in columns 8 and 9 give the calorific values in centigrade units.
 (3) The samples numbered 1, 2 and 3 are different samples of the same coal.
 (4) The first twelve samples are from a South Coast Electricity Supply Station, and the cost delivered in Bunkers are correspondingly high.

APPENDIX II

TABLE II
HEAT IN B. T. H. UNITS CARRIED AWAY BY WASTE GASES, PER POUND OF FUEL BURNED.¹
Specially calculated for "Smoke Prevention."

Temperature °F.	Percentage of CO ₂ in Exit Gases														
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
200	1095	884	739	639	562	503	456	418	385	358	334	314	294	274	254
300	2190	1760	1479	1279	1125	1007	913	836	770	716	669	628	587	546	505
400	3285	2654	2219	1919	1687	1510	1369	1254	1155	1071	1003	942	881	820	759
500	4380	3539	2959	2559	2250	2014	1829	1673	1540	1433	1338	1257	1176	1095	1014
600	5475	4424	3694	3199	2812	2518	2283	2091	1925	1791	1672	1561	1450	1339	1228
700	6570	5309	4439	3839	3375	3021	2739	2509	2310	2149	2007	1886	1765	1644	1523
800	7665	6193	5179	4478	3937	3525	3166	2927	2695	2507	2341	2200	2059	1918	1777
	8760	7078	5919	5118	4500	4028	3652	3345	3080	2865	2676	2514	2352	2190	2028

¹ Calculated for a Bituminous Fuel containing 73 per cent. C, 4.8 per cent. H, 7.3 per cent. O, and .3 per cent. ash in dry state, and 5 per cent. moisture when charged. Specific heat of exit gases (calculated) lies between 289 and 245.

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TABLE III
PERCENTAGE OF FUEL WASTED, BY HEAT LOSSES IN EXIT GASES, AT VARIOUS TEMPERATURES.¹
Specially calculated for "Smoke Prevention."

Temp. °F.	Per. range of CO ₂ in Exit Gases														
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100	8.1	6.5	5.4	4.7	4.1	3.7	3.3	3.0	2.8	2.6	2.4	2.3	2.2	2.1	2.0
200	16.2	13.1	10.9	9.4	8.3	7.4	6.7	6.1	5.7	5.3	4.9	4.6	4.4	4.2	4.0
300	24.3	19.6	16.4	14.2	12.5	11.2	10.1	9.2	8.5	7.9	7.4	6.9	6.5	6.2	5.9
400	32.4	26.2	21.8	18.9	16.4	14.9	13.4	12.3	11.4	10.6	9.8	9.2	8.7	8.3	8.0
500	40.5	33.7	27.3	23.0	20.8	18.6	16.8	15.4	14.2	13.2	12.3	11.6	11.0	10.6	10.2
600	48.6	40.3	32.8	28.3	24.9	22.3	20.2	18.7	17.1	15.9	14.8	13.9	13.2	12.7	12.3
700	56.7	45.8	38.2	33.1	29.1	25.6	23.5	21.6	19.9	18.5	17.2	16.2	15.4	14.8	14.3
800	64.8	52.4	43.7	37.8	33.2	29.7	26.9	24.7	22.8	21.2	19.7	18.5	17.5	16.7	16.1

¹ Losses calculated for a coal containing 7,500 Centigrade units, equal to 13,500 B. Th. Units.

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TABLE IV

ACTUAL LOSSES INCURRED IN MOST BOILER PLANTS AS AT
PRESENT WORKED, DUE TO LOW PERCENTAGE OF CO_2 IN
THE WASTE GASES.¹

Tons of Coal Burnt per Day of 24 Hours	Tons per Day	Waste of Fuel	
		Tons per Year of 330 Working Days	Money Value of Loss per Year £
10	1	330	132
25	2½	825	330
50	5	1650	660
75	7½	2475	990
100	10	3300	1320

¹ *The Engineer*, May 2, 1902.

NOTE.—The above table is based on the assumption that a 10 per cent. loss, of heat and fuel, which might be avoided, is occurring with the exit gases, and that slack at 8s. per ton delivered in bunkers is being burned under the boilers. The money value of the loss will of course increase with coals of higher value.

Appendix III.

MISCELLANEOUS EXTRACTS.

- A. GOUTAL'S FORMULA FOR CALCULATING THE CALORIFIC VALUE OF FUELS, FROM THE RESULTS OF THE APPROXIMATE ANALYSIS.

Formula.

$$P = 82 C + a V.$$

P = Calorific value in Centigrade units. C = per cent. fixed carbon. V = per cent. volatile matter. a = a variable coefficient, depending upon the amount of ash and moisture in the fuel.

Using the formula $V^1 = \frac{V \times 100}{C + V}$, the following values are obtained for a.

$$V^1 = 5. \quad 10. \quad 15. \quad 20. \quad 25. \quad 30. \quad 35. \quad 38. \quad 40.$$

$$a = 145. \quad 130. \quad 117. \quad 109. \quad 103. \quad 98. \quad 94. \quad 85. \quad 80.$$

Comptes Rendus, Sept., 1902.

Sc. Abstracts, No. 252, 1903.

- B. EXTRACTS FROM MR. C. E. STROMEYER'S 1902 MEMORANDUM TO THE MANCHESTER STEAM USERS' ASSOCIATION.

It is evident, therefore, that far greater losses can be incurred by bad stoking with excess of air than with too little air, and there is, therefore, no harm in aiming to attain perfect combustion, more particularly as smoke at once reminds one that the combustion is growing too imperfect. This advice does not apply to gas-fired boilers. Gas, being smokeless, would not be visible, though it travelled up the chimney unburnt. Gas firing has, therefore, always to be regulated by analyses of the waste products.—B. 9.

APPENDIX III

Perfect combustion is of far more importance, both as regards the efficiency of a boiler and the power to be got out of it, than is, within limits, either the amount of heating surface, or its arrangement.—P. 32.

C. RULES FOR SAMPLING FUEL.*

As each barrow load or fresh portion of fuel is taken from the pile or store heap, a count is kept of the number used, and *the whole contents of each tenth or twentieth barrow, or portion*, are placed on one side, in a cool place, under cover. Care must be taken that the barrow or portion selected for the sample, does not contain an unfair proportion of lumps or smalls.

At the end of the day, or period, for which the sampling is to be carried on, the heap of fuel obtained for sampling purposes, as described above, is transferred to a sampling plate, and the larger lumps are all crushed down to walnut size. Should no sampling plate be available, four of the iron plates used for covering man-holes and boiler-flues may be utilized to obtain a *hard clean* surface on the floor of the boiler-house, and the crushing down of the sample may be carried out on these plates, with any heavy and flat lump of iron at hand. The heap of fuel, after this first crushing, is thoroughly mixed by turning over and over with a spade. The heap is then flattened down, two lines are made across it at right angles with the edge of the spade, and two of the four opposite sections are selected to form the reduced sample.

The lumps in this are again crushed, the sample is again mixed, and the quartering operation repeated, until about 8 or 10 lbs. of fuel only remain, with no lumps that will not pass through a $\frac{1}{4}$ -in. sieve. Two 1 lb. tins, with ordinary or patent lids, are filled from this remaining heap of fuel, after thoroughly mixing the same with the hands or with a small shovel. One of these tins is to be sent per parcels post to the fuel expert for analysis; the other is to be kept for reference in case of dispute.

* From Liverpool Engineering Society Paper on *Fuel Economy*, Nov. 8, 1901.

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